79
clu

Henry Harding

LETTERS

ON

HYDRAULICS:

A CORRESPONDENCE BETWEEN

E. S. CHESBROUGH, of Mass., AND C. F. DURANT, of N. Jersey,

On the Physical Laws that Govern Running Water,

APPLIED TO A DAM AND MILL PRIVILEGE ON THE HOUSATONIC RIVER, AT GREAT BARRINGTON, MASS.

NEW YORK:
NARINE & CO., PRINTERS, 21 WALL STREET.

1849.

LETTERS ON HYDRAULICS.

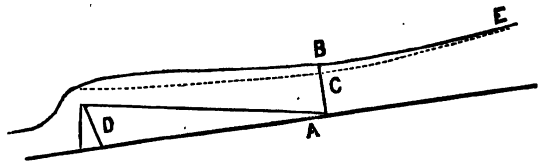
West Newton, May 8th, 1849.

Dear Sir:

Understanding, yesterday, both by letter from, and personal conversation with, Mr. Day, that you were confident I had made some mistake in the calculations which led me to state, that more back-water would be caused by a dam, on the first wheel above it, during high water, than in low stages of the stream; and that you would point out the cause of error, if I would send you a statement of the manner in which the calculations were made,—I shall now give you a brief account of my *modus operandi.*

In order to test the principle in question by calculation, in as simple a manner as occurred to me, I supposed a stream 10 feet wide, with perpendicular sides, and having a perfectly uniform declivity on its bottom. I further supposed this stream to have such a declivity, that when filled to a uniform depth of 2 feet, it would have a mean velocity of 4 feet per second; hence the quantity passing any given point per second, would be 80 cubic feet. From these data, and by using a very simple formula, derived from Eytelwein, $\left(I=\frac{V^2}{8744\,R}\right)$ I make the inclination .00128, or 1.28 feet per 1000 feet.

I next supposed a dam 5 feet high, to be built across this stream, and the pond above it filled; but the quantity of water coming down the stream at the same time, infinitely small, (or, if you please, a state of *extreme low water.*) It is very evident that in this case, the surface of the pond would be level, and the highest point on the stream affected by the dam, would be where its bottom is on a level with the top of the dam—as at A in the figure.



I next supposed a freshet in the stream, raising it to a uniform depth of 2 feet, where unaffected by the dam. Now it is very evident, that if the dam has no more effect in high than in low water, above and at the point A, the depth of the water here will be just 2 feet, and the curved surface of the pond will terminate at C; but my calculations, which have been repeated several times, make the depth A B 2.435 feet, and the termination of the curved surface of the pond, at E, a point I did not reach in my investigation, although the calculations were made to a point about 1100 feet beyond B, where I made the depth of water 2.090 feet.

I calculated the depths of water for every 100 feet, for a distance of 5000 feet, and started with a depth at D of 6.40 feet, making the height of over-fall 1.40 feet—in determining which, I took into account the velocity with which the water approaches the over-fall.

Thinking the rule you gave me, might vary the result, so as to show the principle supposed to exist by the method I adopted, to be incorrect, I applied the rule you gave me at Great Barrington, starting with the same depth at D.—(This, by the way, is a very important matter, and I am satisfied that the depth at the point D, is fixed a little too low; but it favors your view of the question, so far as it varies at all from the precise truth.) From the rule you gave me, I derived the formula, $I = \frac{V^2}{12{,}000\ R}$ according to which the inclination of the supposed stream, when unaffected by the dam, ought to be .000933, or 0.933 feet per 1000 feet, instead of 1.28 feet per 1000 feet. This would make the point A, 5357 feet distant from D, instead of 3906 feet. To my surprise, on calculating the depth of water at the end of the 5357 feet, by your rule, for the bottom inclination of 0.933 feet per 1000 feet, I found it to be 2.424 feet—almost the precise depth obtained at the end of 3906 feet, with a bottom inclination of 1.28 feet per 1000 feet—by the formula derived from Eytelwein.

I have a strong desire that you should go over these calculations yourself, and should like very much to know the result. Please let me hear from you.

Yours, truly and respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

P. S. In looking over your report to Mr. Day, I find you make the declivity of the surface of the stream, in the first 325 feet above the dam 0.19 inch. By my levels, it is just twelve times as great, or 0.19 feet. E. S. C.

NEW YORK, 11th May, 1849.

E. S. CHESBROUGH—

DEAR SIR:

Your letter of 8th inst. is just received. "More back-water would be caused by *a* dam, on the first wheel above it, during high water, than in low stages of the stream." And it is a mistake to suppose that I had disputed that point. And, it is equally certain, that *a* dam can be made (and Day's dam at Great Barrington is of this class,) which, not affecting the first wheel above it in a low stage of water, *it cannot* affect it in any freshet, however high the water may rise.

In the case that you send me, the estimates are based on *a* dam of the precise width of stream. Without examining the calculations, I have no doubt your estimates are there correct, because—

If $R = \frac{a}{p}$

And declivity in 6000 feet $= \frac{V^2}{2R}$

Then a depth of 1 foot in a river 100 feet wide, of even sides and bottom, would require for velocity 3.35, - - - 5.72

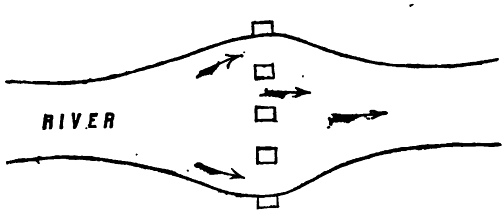
And a depth of 6 feet, with velocity 8.20, would require 6.28

Making a difference in declivity required of - - 0.56

for which there would be no relief.

But if you extend the length of dam, with sluice or gateway, beyond the width of stream at that point, or, make the length of dam greater than width of stream, at *any* point between it and the first wheel above, then the increased declivity is instantly relieved, so far as the dam has any agency in the matter, in lowering the column by increased length. And, if the length of discharge exceeds the width of river by $\frac{1}{5}$, then in the foregoing case, the excess of length will lower the column on dam 0.91, which exceeds by 0.35 the increased declivity caused by the additional five feet of water.

The raising of water by piers of bridges, in a river of equal depth and width, is a good illustration of this principle. When the piers fill up 0.5 of the channel or waterway, it is very evident, from Du Buat, in the foregoing formula, that the piers are *a dam*,—and the greater the flood, the greater will be the amount of rise due to the piers. But, if the river at the bridge, is increased in width, the sum of piers, 0.5, added to the amount required to balance the angle of the new water-way, then the stream must flow on precisely as if no piers had ever obstructed its passage; thus—



In a P. S. you mention a difference from 0.19 by my report, to 2.28 by your survey, in level, near the dam. I have no doubt that both are correct. At the time of your survey, there was an increased flood: a portion of the 2.28, say 0.28, was due to the increased velocity, while the balance, say 2., was entirely due to *a natural dam of rocks and narrowed channel*, of the precise character of a dam of piers; and, if instead of 2.28 inches, you had found 2.28 feet, then clearly *it—the natural dam*, and *not* Day's dam—was the cause of the excess of rise. Suppose the river at that point, to be contracted by natural sides or rocky piers, to 0.5 its present width, then, computation will show us very plainly, that the great difference in level, is *caused by the natural dam;* also, that the lower dam (Day's) may in all cases of greater flood, be raised so much as to *flow that great difference*, without in the least degree affecting the first wheel above.

The subject is replete with interest, and if I have omitted to make myself clearly understood, you must attribute the cause to a desire to be prompt in acknowledging your letter. I shall at all times be most happy to hear from you on this matter.

Yours, &c.

C. F. DURANT.

WEST NEWTON, May 18th, 1849.

DEAR SIR:

Yours of the 11th inst., was received two or three days ago; and I have delayed answering it, in order to give you the result of some investigations I have been making.

We certainly came much nearer agreeing with regard to the effect of a dam, *square* across a stream of regular width and bottom declivity. In such a case, I now understand you to say, that you never disputed the conclusion I have arrived at. You say, however, that if the length of dam be increased $\frac{1}{8}$, (in the case proposed,) the effect to cause back-water on the wheel above, will be entirely done away, *in any stage of the river.*

I have looked into this subject carefully, and made calculations for three new cases. 1st. Where the dam is 50 per cent. longer than the stream is wide. 2d. Where it is 100 per cent. longer; and, 3d. Where it is 1000 per cent. (or 10 times as long.) The result is, they all show an increase of effect, for an increased quantity of water; but the amount of effect diminishes, as the dam is lengthened: very slowly however, after you get beyond double the width of the stream. My calculations, as well as reflections on the nature of the case, irresistibly lead me to the conclusion, that it is impossible to build a dam across a stream, uniform in width as the Housatonic is, without producing this effect in some degree—no matter how curved or oblique the dam may be in its form: provided, of course, there are no perpendicular (or nearly so) falls in the stream. I, of course, mean to include the Housatonic among the cases, where the effect referred to, would be caused by a dam.

You mention the case of a stream being obstructed, and consequently dammed up, by piers, and then widened out so as to prevent

the water from rising any higher than it did before the piers were built, as a good illustration of the effect of making a dam longer than the stream is wide. I cannot see the application, or the force of your illustration, unless you mean to widen out the channel of the stream itself, at and for a considerable above the dam. I have not investigated what the effect would be in such a case; but one thing is very certain, that in ninety-nine cases out of a hundred, no one would ever go to the expense of doing it. I take it for granted that you mean simply lengthening the dam, letting the stream remain its natural width. In this case, I cannot see a strict analogy between a regular dam and piers. As you observed, the effect of piers may be counteracted by widening the stream; but by what means water, which is to flow over a dam, raised above the ordinary or natural level of the stream, can be made to do so, and not stand above the dam any higher than the ordinary or natural level of the stream, in similar stages of water, is more than mortal can explain, (unless resort be had to syphons or machinery.)

I called your attention to the difference of our levels, that you might consider the cause. Of course, a different stage of the river is a sufficient cause for almost any difference of levels; and as you saw the river both times, and I only once, you are of course the better judge.

Any hints or arguments from you on this subject, I should be very glad to hear.

Yours, very respectfully,

E. S. CHESBROUGH.

C. F. Durant, Esq.

Jersey City, May 21st, 1849.

E. S. Chesbrough—

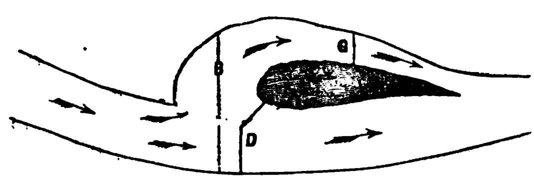
Dear Sir:

When I wrote, "extend the length of dam, with sluice or gateway, beyond the width of stream," I did not mean to extend the dam "obliquely" across the stream.

I agree with you, that to extend the dam merely by placing it obliquely across the river of equal width and depth, would have the

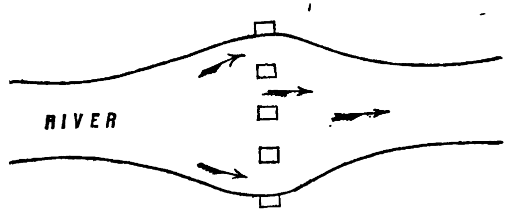
same effect in raising back-water in increased floods, as if it crossed the stream at a right angle; and if the oblique dam extended the whole length of river, the effect would be the same: for if we suppose the river to be 4372 feet long, and dam extending obliquely the whole length, then the amount of back-water caused by each foot of the dam, is equal to I, where $I = \frac{V^2}{8744 R}$

In my letter of 11th inst., I had special reference to Day's dam and gateway on the Housatonic, and to dams of that class, extended beyond the width of river, by widening the stream, thus—



D, the dam, and G, the gateway, are together $\frac{1}{8}$ longer than the width of river. In this case, the increased length given by the angle or oblique direction of dam, has the same effect in lowering the column of water, as if the same increased length was accomplished by further extending the width or water-way of the river; because the angle extends into a basin, B, which is below and wider than the river.

In the case of a stream obstructed by piers of bridges, I meant, to widen out the channel of the stream itself, at and for a distance above the piers, thus—



And I think you will agree with me, that the case is analagous to that of extending the length of dam and gateway beyond the width of a river, by widening the stream at and for a distance above the dam, as shown in the preceding diagram.

In regard to widening the channel, at and for a distance above the piers, you justly remark—"in ninety-nine cases out of a hundred, no one would ever go to the expense of doing it." The same remark

may be correctly applied to nine out of ten persons who build mill dams; for, in a large majority of cases, to save expense, the narrowest part of a river is selected to build both bridges and dams; when, for safety to the bridge, and to guard against increased back-water in a flood, from the dam, the widest part of a river should be selected, or the stream should be widened, like in the case of Day's dam, as shown in the diagram. For the same reasons, a bridge or dam should not be erected at, or immediately above, a turn or angle of deflection in a river; because the angle, like rocky piers, or narrowed channel, is a natural dam, and the greater the flood, the greater will be the amount of rise or back-water due to the angle.

The levels in your survey, present the best possible illustration of the advantage in selecting the widest part of the stream for a dam, or in extending the dam and gateway by widening the stream. In your levels, as I understand, you found 2.28 inches on the section next to the dam, where, in a lower stage of water, I found only .19; this .19, I find on reference to my survey, was 325 feet distant from Day's dam, or about one-fourth part of the whole distance between the dam and first wheel above, where you found the entire amount of level 5.24 inches, or thereabout. Now, by all the laws that govern running water,—and no matter what coefficient we may employ, whether $I=\frac{V^2}{8744\,R}$ or $I=\frac{V^2}{12000\,R}$ or $I=\frac{V^2}{650\,R}$ or if we make declivity in 4372 feet$=\frac{V^2}{2\,R}$ or declivity in 6000 feet$=\frac{V^2}{2\,R}$ or declivity in 325 feet$=\frac{V^2}{2\,R}$. In either, and in every case, the dam by increasing the value of a in $\frac{a}{p}=R$, must, so far as its influence extends, make the quarter section next to dam, positively *less* than the one-fourth part of the whole 5.24, or *less* than 1.31; while your survey shows that it is in fact 2.28, a sum much *greater* than the fourth part of the whole 5.24,—and giving the most positive physical proof, that a natural dam of rocky piers, or angle of deflection, or narrowed sides, or the whole combined, had raised the surface at that point; and showing most positively the physical impossibility of Day's dam causing the increased height.

The best apology that I can offer for troubling you with so much minutiæ, is, that the love I bear to this branch of physical science,

prevents my knowing where or when to cease writing. I commenced this letter in the evening, and it is now nearly one o'clock, A. M., Tuesday, but I shall leave the date where I began.

I shall be happy to hear from you at your earliest leisure.

Yours, &c.

C. F. DURANT.

West Newton, May 25th, 1849.

Dear Sir:

Yours of the 21st, was received yesterday morning, and I intended to answer it in detail, by to-day's mail; but in consequence of business matters, and our inconvenient mail arrangements here, am afraid I shall not be able.

It is very gratifying to me, that what appeared at first a world-wide difference of opinion between us, has narrowed down to so small a compass. I feel now, that our discussions have led us to a point, from which we both clearly see wherein we do differ; and must soon lead us to an entire agreement, or to the discovery of fundamentally different views, with regard to mathematics or physics.

Yours, truly and respectfully,

E. S. CHESBROUGH.

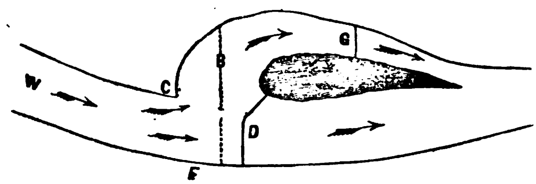
C. F. Durant, Esq.

West Newton, May 25th, 1849.

Dear Sir:

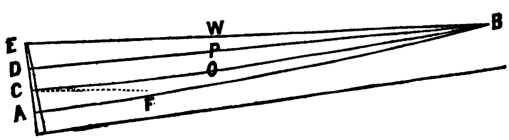
Being desirous to answer your letter of the 21st, without extending my communication beyond the limits of this sheet, I shall pass over some subjects you mention, they being matters about which we do not differ.

Fig. 1.



With regard to the effect of widening a stream just above a dam, to prevent back-water,—while I admit that in proportion to the actual widening of the stream, not only at the dam, but for a considerable distance above, will be the effect to diminish back-water,—I feel satisfied that nothing which has been done, or can be done at a reasonable cost, at Day's dam, can, while it remains at its present height, prevent it from causing back-water, in high stages of the river, on the B. W. Co's wheel. Admit, if you please, that the canal at G, and the angle in the dam at D, should double the capacity of the river (not the overfall) below C, to discharge water, and that the distance from C to D, is one-tenth the distance between W and D: then the greatest possible effect it can have, is to diminish the natural declivity of the stream one-half between C and D, or $\frac{1}{20}$ the whole declivity between W and D, supposing it to be uniform the whole way. But, as you are aware, the lower part of the ponds, above all ordinary dams, has less declivity than the upper part, consequently the saving in this case, would be less than $\frac{1}{20}$ the whole declivity. But a saving of $\frac{1}{20}$ at C, by no

Fig. 2.

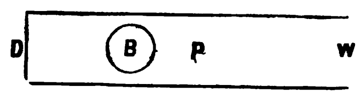


means secures $\frac{1}{20}$ at W, as will be seen by the above figure. Suppose a stream with a uniform declivity and depth, and with its surface A B to have a dam built across it that would raise the surface of the water to C; then the declivity which the surface of the stream would take, would not be the horizontal line C F, and the straight inclined one F B; but, as the formula $I = \frac{V^2}{12000\ R}$ shows, would be a curved line, as represented by C O B; or if the dam raise the water to D, then by D P B; or if to E, then by E W B. Now it is very evident, that W P cannot be equal to E D, nor P O to D C. But the distance C D (see Fig. 1,) I know to be less than $\frac{1}{10}$ W D, and you do not claim that the stream is widened from C to D more than $\frac{1}{6}$. Hence it is impossible, in this view of the case, that the whole saving of declivity, can be as much as $\frac{1}{20} \div \frac{1}{6}$, or $\frac{1}{120}$. A much greater saving than this is no doubt due to the lengthening of the *over-fall* at D; but I have already shown, that no lengthening of an over-fall, can do away entirely the effect of back-water above a dam, no matter what the form

of over-fall, whether it have a straight and oblique direction, be angular like one, or (if you please) several, mitres.

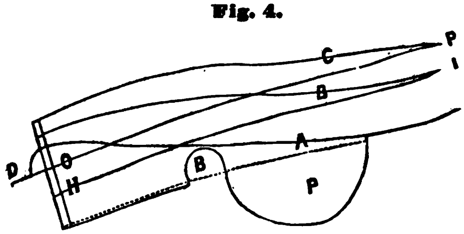
You infer that because in a low stage of the river, the declivity in the first 325 feet was only 0.19 inch, and in a high stage is 2.28 inches, that the natural barrier in the river, and not Day's dam, causes the difference. No doubt such a *difference* existed in high and low stages of the river, before the dam was built; but that the dam has nothing to do with raising the surface of the water to its actual height, in high stages of the river, cannot possibly be proved. Suppose Fig. 3, to

Fig. 3.



represent a plan of a stream, obstructed by an artificial dam D, and by a natural barrier, or rock, B. Suppose Fig. 4, to represent a pro-

Fig. 4.



file of this stream, with its irregular bottom and pool P, above B. Now it is evident, from an application of your own formula, as well as from the nature of the case, that in extreme low water, the line D A would represent the surface of the stream; in ordinary stages, the line D B would, and in higher stages, the line D C would—each of the two last showing a more than average declivity in passing the barrier B, and less than the average over the pool P.

Let us suppose next, the dam is removed, and the surface of the river restored to its natural state; then it will be represented in its different stages by the dotted lines H I and O P—showing that while in a natural state, the declivity required to pass the obstruction B, is greater than if the dam D were standing—the actual height of the surface of the water is less. Your conclusion, therefore, that Day's dam does not cause "the increased height" above the rocky barrier, on the first 325 feet above it, I think you will, on reflection, see must be erroneous. In your printed letter to Mr. Day, you say that his

dam probably raises the water several inches in the lower end of the B. W. Co's tail-race, and this is far above the rocky barrier, or obstruction, we have been speaking of.

I should like very much to have the elements you used in estimating the declivity required above Day's dam—that is, the width, depth, and quantity of water passing per second,—if you have preserved, or can recollect them. Please favor me with them.

Yours, very respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

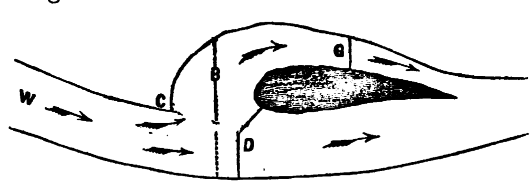
NEW YORK, May 28th, 1849.

E. S. CHESBROUGH—

DEAR SIR:

Your letter of 25th inst., is this moment received. The river is widened, *not* to prevent back-water, but to prevent any *additional* back-water that might otherwise be caused by an increased flood. The back-water, or declivity required to pass the stream in a low stage of water, was provided for in the original construction of Day's dam: in this I understand that we agree.

Of your Figure No. 1—



you say, "If you double the capacity of the river below C, to discharge water, then the greatest possible effect it will have, is to diminish the natural declivity one-half, between C and D, or $\frac{1}{20}$ the whole declivity between W and D, assuming W and D to be ten times C and D."

The distance between C and D is of no consequence, so long as it is ample to maintain a column of water of equal height throughout, on every inch of dam and gateway; and the effect is not to "diminish," but to increase the declivity between C and D. One moment's reflec-

tion on the law of falling bodies, or by inspecting Du Buat's table for the quantity of water discharged over a weir, computed from that law, you will see that in the case you proposed, a column of water 22 inches high, will instantly fall to about 12 inches, when extended to double the length, as proposed, and thus increasing the declivity by lowering or diminishing the column 10 inches, or about $\frac{5}{11}$ of the whole 22 inches; and this fall must extend to near the river at C, where there is no dam, except its own sides and bottom, which, by Du Buat, form a dam of infinite length, or as far as the river extends; and where there can be no increased back-water due to dam, but an actual diminution of the whole flood.

Your Figures, Nos. 2, 3 and 4, as I understand them, are to show, that if Day's dam were removed, then the surface of water, at a point distant 325 feet from dam, would be lower than it now is. I do not dispute that. My reasoning was to show, that the increased rise at that point, was not due to Day's dam, but was due to increased flood, with increased velocity, acting on or creating, (if the word is applicable,) a natural dam of narrowed sides, or rocky piers, or angle of deflection. All the rise at that point—325 feet from dam—that can be due to the dam in increased floods, was provided for in fixing its original height. If Day's dam was removed, an *increased* flood would cause an *increased* back-water on first wheel above, to the extent of whatever rise is due to the increased quantity of water obstructed by sides, bottom, and angle of river.

All the elements preserved, you will find in printed report and in letter to Emerson. The quantity of water, was computed from Du Buat's table for discharge over a weir. I shall be pleased to hear further from you.

Yours, &c.

C. F. DURANT.

WEST NEWTON, May 29th, 1849.

DEAR SIR:

I sent my report and accompanying drawing, to Mr. Day, by express, yesterday, and at the same time mentioned in a private letter, that I would cheerfully correct any errors you or any one else, might point out. The case is not to come on before the 19th of June—just three weeks from to-day,—and this will give ample time for examina-

tions and revisions, if necessary. I hope you, at least, if Mr. Day should not employ any one else, will give every part of my report a thorough overhauling, and will freely disclose to me any errors you may discover, or point out obscurities that need clearing up.

In my last letter to you, which was written after bed-time, I made an error, in stating, that if the stream at Day's dam were doubled, the declivity would be diminished one-half. It would be diminished about three-fourths. The diminution is as the *square* of the width, and not directly as the width, as I carelessly stated it. The amount of the error, however, when the width is only increased one-sixth, is so small, as not to have an appreciable effect upon the height of water near the B. W. Co's wheel.

Yours, truly and respectfully,

E. S. CHESBROUGH.

CH'S F. DURANT, Esq.

WEST NEWTON, June 2d, 1849.

DEAR SIR:

Yours of the 28th ult., was received on the 30th; but my engagements have been such as to prevent me from answering it earlier.

In my letter, to which your last was an answer, I took special pains to add a note, to prevent you from supposing that I meant, the doubling of the *over-fall* would not lower the water at the dam more than $\frac{1}{20}$ the whole declivity, between W and D; but to my surprise, you have written as if I had added no such note. I meant that the simple widening of the stream, *independent* of the over-fall, could not possibly diminish the declivity between C and D, over $\frac{1}{20}$ the whole declivity between W and D—(It should have been $\frac{3}{40}$, as I have since acknowledged to you.) It was, perhaps, absurd to talk of widening the stream, without lengthening the over-fall; but my reason for considering the two, independent of each other, was because you had no confidence in long oblique dams preventing back-water. I differ from you here, however, and have great confidence in oblique dams *diminishing* the effect of back-water on the first wheel above, though I have not the slightest faith in any dam *across* a stream, in any direction, or of any shape whatever, *annihilating* the effect of back-water on the wheel above, in all stages whatever of the stream.

You say—" by one moment's reflection on the law of falling bodies, or by inspecting Du Buat's table for the quantity of water discharged over a weir, computed from that law, you will see that in the case you proposed, a column of water 22 inches high, will instantly fall to about 12 inches, when extended to double the length, as proposed," &c.

I do not possess a copy of Du Buat's tables; but it is perfectly easy to calculate what the height of water at an over-fall should be, supposing the length to be 100 feet, and the quantity 800 cubic feet per second. I make it, as you say, 22 inches—supposing the weir to be a notch in the side of a reservoir of very great extent, so that the water has comparatively no velocity till it reaches the vicinity of the over-fall. If such a weir were doubled in length, I estimate the height of the water on the over-fall at 1.01 feet, or about $12\frac{1}{8}$ inches. But you leave out of view one very important fact, equally connected with the law of falling bodies, and that is, the velocity of the surface of the stream, above the immediate influence of the over-fall. The average depth of the Housatonic, just above Day's dam, being for the case I supposed, about 5 feet, the depth of water on the over-fall would be but $16\frac{2}{3}$ inches; and were the length of over-fall doubled, the depth of the stream above the dam, remaining the same—less the difference in depths on the over-fall—it would be $11\frac{3}{8}$ inches, making an actual difference of only $5\frac{7}{24}$ inches. But if the over-fall and river be made only $\frac{1}{8}$ longer, and wider, then this difference will be diminished to $1\frac{5}{12}$ inch. Even this difference will be considerably less before you reach W.

My Figures, Nos. 2, 3 and 4, were designed to show, that if Day's dam were removed, there would be a fall in the surface of the water, not only 325 feet above the dam, but a gradually diminished fall, as you proceed up stream, even to beyond W. You acknowledge yourself, in your letter to Mr. Emerson, (not as I supposed when the next to my last was written to you, in your printed letter to Mr. Day,) that Day's dam probably does cause several inches more in depth of water, at the end of the B. W. Co's tail-race, than would be there, if the dam were removed. This point, as you are aware, is more than 900 feet above the dam.

You speak of an *increased* flood causing an *increased* depth of back-water on the B. W. Co's wheel, if Day's dam were removed. The law which you refer to here has, within certain limits, the effect you speak of; but an unreflecting person might suppose from the language

used, that if Day's dam were removed, the water would stand higher, in times of freshets, at the B. W. Co's wheel, than it does now—a conclusion so preposterous, that I have not the slightest idea you entertain it. If you would build a dam high enough to submerge the B. W. Co's wheel entirely, *(at low water,)* still the *increased* amount of back-water, by an *increased* flood, would probably be diminished.

I look upon this question as one of very little, if any, practical importance to Mr. Day. The all important question to him, in my opinion, is,—Would the removal of Day's dam diminish the actual depth of water at the B. W. Co's wheel, in high water?

Yours truly, &c.

E. S. CHESBROUGH.

CH'S F. DURANT, Esq.

Excuse haste.

P. S. The elements I wished, were not to be found in the book you mentioned. They are the width of the river, (which I believe you assumed at 100 feet uniformly,) and the average depths at the different sections you included in your calculations, and the quantity or cubic feet of water per second.

Formula for calculating depth of water on over-fall:

$$\frac{Q}{L}=H\left(a\sqrt{2gH}+V'\right)$$

In which Q=quantity passing per second; L=length of over-fall; H=depth required; a=practical coefficient, usually assumed at 0.4; and V'=velocity of surface of the water—say from 30 to 100 feet—above the over-fall.

This is rather an inconvenient rule to work with; but by the method of approximations, is easy to get at a correct result in a short time—a result, too, which I find agrees remarkably well with observations.

BOSTON, June 4th, 1849.

Your review of my report has been received, and I 'll try to send a reply to-morrow.

JERSEY CITY, June 2d, 1849.

E. S. CHESBROUGH—

DEAR SIR:

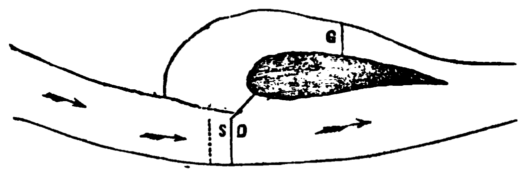
I have examined with much care, your report to Mr. Day, on the physical influence which his dam at Great Barrington may have on the waters flowing in the Housatonic; and I now avail myself of your kind invitation, to point out such errors as I may deem of importance.

In the profile, you have placed the bed of the river at dam, nearly 4 feet below the average top of dam; by this you undoubtedly mean to give the bed of race-way, as part of the river: in that there is no objection, so far as regards actual or estimated levels and inclinations, existing at the date of your survey; but when you estimate, as you have there done, for levels and inclinations that would have existed in the Housatonic, "on 23d April, if Day's dam had been removed," then, it is an error to assume the race-way to be part of, or its bed to be the bed of, the Housatonic. The race-way, is an artificial construction—it is part and parcel of Day's dam; they were constructed together, and in all estimates for inclinations in the natural flow of water in the Housatonic, both the dam and the race-way must be removed together, or mathematically, they must be estimated together as nothing.

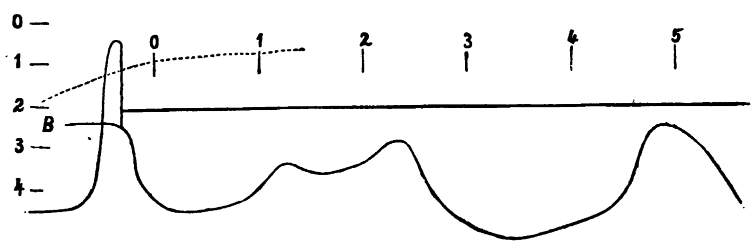
Day's dam was erected precisely 1 foot 11 inches above the bed of the Housatonic: for this fact, you have Mr. Searfoss' statement, the measurement of the dam itself, and a durable monument of rocky bed, the remains of a very ancient dam at that point. One of the rocks, a boulder of no mean proportions, projecting far above the bed, now forms a bulk-head, or support to the dam.

Your dotted line, showing surface of water, estimated at 2 feet deep, in case Day's dam was removed, is placed 10 inches below top of average dam. Now, a depth of 2 feet of water on the natural bed, at that point, must reach 1 inch above a dam of 1 foot 11 inches, and would make the surface of water 11 inches higher than you have placed it. This is an important error, and you will see that it is fatal to all your estimated levels for removal of dam. A revision of this matter will convince you, that 800 cubic feet of water per second—the amount which you give as the basis of all your calculations—could not pass that point, on the natural bed, with a velocity of more than 2.34 per second, and requiring a depth of 3 feet 5 inches. This will raise your estimated dotted line for surface, to 1 foot 6 inches above average

dam, and will increase the amount of your error from 11 inches to 2 feet 4 inches. For better illustration, I refer to the following diagram·



The dotted line, showing the course of river, if dam and race-way were removed, and the Housatonic restored to its original or natural flow. S, section of river at dam, would be less than 100 feet, but assume it at 100 feet, then, 800 feet per second, at velocity 2.34, would require a depth of 3.4 feet, or 3 feet 5 inches, within a small fraction, and, by the following diagram copied from profile in your survey.



B, the bed of Housatonic and base of dam, is, you will perceive, three inches higher than bottom of river, at 450 feet from dam; and if in a revision of your report, you do not find the same apparent anomaly which you found at 200 feet from dam, you will at least, I think, find it difficult to give a velocity greater than 2.34 to the water at S, in the first diagram—where, instead of a perpendicular dam or weir, it must pass over some considerable distance of rough and rocky bottom.

This estimated correction of your error, as you must perceive, will raise the surface to over two inches above where it stood by your survey on the 23d April, with the dam up, and to near the point where it stood with 3½ inch flash boards on. This apparent anamorphosis, or positive paradox, is the base of all our disagreement,—a disagreement of serious importance; affecting not only the pecuniary interest of two mill owners, but also as an important question of science,

affecting the truth for all time. I yet believe, that in a full understanding of the difference existing, we will come, not only to a perfect agreement in all that relates to the levels as they now exist, and as they would exist, if Day's dam and gateway were removed from the Hosatonic, but we will also, I think, agree in awarding due merit to Mr. Searfoss, the unassuming mill-wright, whose ingenuity has secured all the fall due to a low stage of water, without affecting the first wheel above, in any freshet, however high the water may rise.

The correction in your letter of 29th May, does not reach the mistake in your letter of 25th. The lengthening of a dam by widening of the stream, does not "diminish" the declivity, as you there state; but the effect is to lower the column of water on dam, and thereby increase the declivity. I have not yet received a reply to my letter of 28th, in which I explained the cause and effect produced in such a case.

I regret that you did not make it convenient to state in your report, the precise height of water at which Day's dam flowed o without encroaching on first wheel above. If you had stated that point, I could then more readily show, that *for all increased floods*, Day's dam and gateway would increase the declivity, and thereby lessen the height of flood or back-water on first wheel above, until the dam ceased to be a dam, (a paradox,) or until the flood will pass over the top of the dam itself, at the precise height at which it would have passed, if dam and gateway had never been built. If you do not irresistibly embrace this view, when correcting the error in your report, of dotted lines for height of flood "on 23d April, if Day's dam had been removed," then, I will illustrate it further and in detail. I wait your reply.

Yours, &c.

C. F. DURANT.

P. S. The red lines on profile, showing height of water with flash boards on and off, are a matter of some collateral importance in this discussion. The boards, I believe, were 3½ inches wide, and you must recollect that they did not raise the water 3½ inches, as you have stated, or even two inches at dam, until you closed the sluice or gateway—the great coefficient, or compensating balance, which is *not*, and never was, a part of the Housatonic.

C. F. D.

West Newton, June 4th, 1849.

Dear Sir:

Your review of my report was received this morning. It is now after bed-time, but I must commence my reply to-night, for my engagements to-morrow will prevent me from writing much then.

Perhaps you will think my perceptions very obtuse; but I must confess my inability to see the "errors" you have pointed out. The main strength of your whole argument is based on the *baseless* assumption, that if Day's dam were removed, the velocity of that part of the river would be 2.34 feet per second. I say baseless—for you did not give a single proof that it would be so; and to my own mind, nothing could show the absurdity of it more conclusively than the inferences which inevitably flow from it, and which you yourself make: that is, if Day's dam were removed, the water would stand higher there, than it does now. If Day's dam was built on the remains of a much older one, which was 23 inches uniformly lower than the present one, (which I do not mean to dispute, though it is difficult to see how, with such a rocky bottom, any one could tell what its height was,) then I say, that the velocity would be much nearer 8 feet per second than 2.34. My proof is this: according to your own showing of the height of the ancient dam, and what I know to be the state of the river below, there is a declivity on the bottom of the stream, of not less than one—most probably two—feet, in the first 10 feet below the dam; but suppose it only 1 in 20,—and let us call the perimeter in contact with water 1000 feet, instead of 100 feet,—then, from your own formula, it is demonstrable, that for a surface parallel with the bottom, the depth would be but 1.03. But you will say, there is no probability that the surface would be exactly parallel with the bottom for any distance, and I grant it;—what it would be exactly, would require a tedious process to ascertain. I had no doubt, while at Great Barrington, that the removal of Day's dam, would immediately lower the surface of the water there upwards of 2 feet; but since receiving your last, I have concluded not to trust to memory, or to mere sight, and have taken steps, for my own satisfaction, to have certain levels and measures taken.

From an entire misconception of my views with regard to the effect of widening the stream at Day's dam, you speak in your two last, of the declivity of the stream being *increased* thereby. In my last, you will see that I took special pains at the time, to prevent such a misconception.

If Mr. Day is willing to incur the expense, I will have an estimate made of the precise quantity of water that might flow over his dam without causing back-water on the wheel above; but as it would require several days to do it—being a very intricate problem—I do not feel justified, with my present engagements, in undertaking it.

I should be gratified to know where and when I stated, that flash floards $3\frac{1}{2}$ inches high, raised the water $3\frac{1}{2}$ inches. Please, in your next, quote my words, if they have been written in any letter to you, or in my report. My statements of observations, show what the effect of flash boards was, and whether Day's wheel was stopped or not.

Yours, truly and respectfully,

E. S. CHESBROUGH.

C. F. Durant, Esq.

Jersey City, June 6th, 1849.

E. S. Chesbrough—

Dear Sir:

In your letter of 2nd inst., you say that you "have not the slightest faith in any dam *across* a stream, in any direction or of any shape whatever, annihilating the effect of back-water on the wheel above, in all stages whatever of the stream."

Such a dam would indeed be a talisman as potent as a famous lamp in Arabic story, and if placed before a submerged wheel, it might, by annihilating the back-water, create a water power and fall where no power or fall had previously existed. We will not disagree on that point.

In regard to the quantity of water discharged over a weir, you say that I have "left out of view the velocity of the surface of the stream, above the immediate influence of the overfall." If by that you mean that I pay no regard to velocity of stream when computing the discharge of water, by the law of falling bodies from the height of column on weir, on dam, or on notch in reservoir, then you have understood me correctly. I will add, that in my opinion, those modern writers on Hydrodynamics, who involve velocity of stream with height of column, in constructing formulas for computing the discharge over a weir or dam, are neither facilitating a knowledge of

science or adorning the simple truth. The law of falling bodies, involves motion uniformly *accelerated;* the horizontal motion of a stream being at a right angle to a perpendicular fall, is clearly ***no acceleration*** to the descent or gravitating force of the column, and therefore, it is ***not*** "a fact equally connected with the law of falling bodies." Water discharged over a dam or weir, is matter falling in space; the motion of the stream or horizontal velocity, is due to the height of the falling column; and hence area and velocity only are involved together. When we know the height of column alone, we can compute the area and velocity involved together; and when both height of column and area are known, we can then, and not till then, compute the velocity with mathematical truth. Hence, you must see that your case "supposing a weir to be a notch in the side of a reservoir of very great extent, so that the water has *comparatively no velocity* [italics are mine—C. F. D.,] till it reaches the vicinity of the overfall," does not elucidate the subject in the least; because the velocity whether small or great, is always involved in the area, and is due to the height of column or "overfall" on weir or dam; for if the column is closed on weir or dam, then the velocity must cease to exist. You say "the average depth of water just above Day's dam, being for the case supposed, about five feet, the depth of water on the overfall, [column] would be but $16\frac{2}{3}$ inches." Now you must perceive from what I have already said in regard to the law of falling bodies, that if the depth of water was there 5000 feet deep instead of five feet, it could not increase or diminish the height of column, or overfall, on dam. And hence, in extending a dam and gateway by widening a river, it is sufficient when the area at basin can maintain on each and every inch of extended dam, a column of water of the height required by the law of falling bodies, to discharge the actual quantity of water passing the river; and hence, it is an error to suppose that a column of $16\frac{2}{3}$ inches will fall to only $11\frac{3}{8}$ inches, when weir or dam is double in length; and it is a very great error to suppose the difference "will be diminished to $1\frac{5}{12}$ inches if the overfall and river be only $\frac{1}{8}$ longer and wider. Of this fact you had ocular demonstration, when in April last, the closing of a gateway equivalent to less than 10 feet length of overfall, less than $\frac{1}{11}$, raised a 17 inch column, $1\frac{1}{4}$ inches on Day's dam of 112 feet long. In regard to lowering the column by increasing length of dam and gateway, you remark "even this difference will be considerably less before you reach W." Well,

suppose it is less before you reach W., or suppose it is nothing before you reach wheel above, what has that to do with Day's dam? Day's dam, or Mr. Day himself, as I understand this question, must *not cause* back-water on wheel above; it is not necessary that Day's dam should annihilate or even lessen any back-water that is caused by the natural flood acting on sides and bottom of a natural river. It is sufficient if his artificial dam and raceway do *not* cause any, or do *not* add any back-water to that which is due solely to the natural flood and natural river. Day's dam does probably in a low stage of water, raise the surface several inches at foot of B. W. Co's tail-race; but in all increased floods, the remotest point influenced by dam, can never recede from, but must continue to approach to the dam, until the water will flow over the dam itself, at the same height that it would flow, if dam and gate-way were removed, and the river restored to its natural bed.

If Day's gate-way is to remain as part of the Housatonic, then, in all stages of flood, whether high or low, the removal of his dam would lower the surface at every point between it and first wheel above, until the increasing flood, resisted by sides and bed *of river below dam*, would rise in the gate-way itself to the precise height at which it would have stood, if channel of gate-way were filled up, and river restored to its natural bed. But Day's gate-way is an artificial, not a natural stream: it has accomplished the purpose for which it was intended, while it prevents any additional back-water that might otherwise be due to an increased flood, where a *narrowed* channel would raise the water independent of the dam proper.

You understood me correctly, when you understood me to mean, "that if Day's dam [and gate-way] were removed, the water would stand higher in times of freshets, at the B. W. Co's wheel, than it does now,"—however "preposterous" such a conclusion may seem. I presume the owners themselves, of B. W. Co's wheel, and many others, will tell you, that before Day's dam was built, the B. W. Co's wheel was frequently submerged to its centre; while your experiments with flash boards, did not submerge the wheel to within two feet of the centre. I do also mean, that if Day's dam and gate-way were removed, and *the river restored to its natural bed*, at the time of your survey, the surface of water would then have been quite as high as it then stood.

I had written thus far, when your letter of 4th inst., was brought to me a few minutes since. You there express great desire to know "where and when you stated that flash boards 3½ inches high, raised the water 3½ inches." In your report to Mr. Day, you submit as part of that report, "a plan and profile," on which you state, "the upper and lower red lines show the surface of the river as it was April 29th,—flash boards on and off." The red lines there clearly show 3½ inches, on a scale so large as to prevent a possibility of mistake.

To infer, that if Day's dam were removed, and the river restored to its natural bed, "then the water would stand higher than it does now," is neither "baseless," or an "absurdity." If in this very important question, you had first ascertained the proper elements, width, depth, and height of the natural Housatonic, at and below dam, then, and not till then, you would have had a base for your otherwise "baseless" "*estimated surface of water—would have been, April 23d, had Day's dam been removed.*" To attempt such an estimate without the proper elements, and give the result to the world, as the professional estimate of an eminent engineer, is trifling with a great truth. I rejoice that you have taken steps to ascertain the required elements for that estimate, and I am not without hope that we shall then come to a perfect agreement. I am desirous to hear from you on this subject.

Yours, &c.

C. F. DURANT.

West Newton, June 12th, 1849.

Dear Sir:

Your last communication was received on Saturday; but it has not been convenient for me to answer it before now. There is much in your letter that might be noticed; but my time will not justify me in making the attempt—neither does my inclination prompt me.

The important points to be noticed,—and in my opinion the only important ones—are, the question whether the velocity with which a stream approaches a weir, should be taken into account or not, in calculating the quantity discharged over the weir; and, the correctness of my

statements with regard to the height of the dam,—and the effect that would be produced *there* by its removal.

With regard to the first question, I have not only my own knowledge of the properties of falling bodies, (perhaps too limited,) but I have the evidence of observations repeated on a large and most satisfactory scale; and the testimony of the highest scientific authority, both in this country and in Europe. In the Encyclopedia Metropolitina, vol. (or part) III, July, 1818, page 238, and section 132, you will find these words just below a table of computed quantities discharged over a weir:—

"The above column is computed on a supposition that the water from which the discharge is made, is in a state of stagnation; and if therefore, it reach the opening with any velocity, we must multiply the opening by the velocity of the stream, and the above discharge will be increased by a quantity equal to that product."

With regard to the dam, my brother's measurements sustain me in what I have said. I had before the evidence of my eye-sight, that it was so; but after what you said, I wished, in case of necessity, to be able to say *to the world*, that an instrumental measurement had been made. In haste.

Yours, truly and respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

P. S. I came near forgetting to say, that the "ocular demonstration" you say I had in April, that Day's race-way, when closed, raised the water in the river 1¼ inches, has entirely escaped my mind, if it ever had a lodgement there. The recorded observations of April 20th, when the gate was closed twice and opened twice, show that the greatest effect was to raise or depress the surface ¾ of an inch at A, a point entirely too near the head of the race, to give a fair test; for at no other observed point above, was the change produced, greater than half an inch.

I will not attempt to deny what you say about the "red lines" at the dam being 3½ inches apart; for I have painful evidence in the copy preserved in my office, that my assistant has made the mistake you mention. It should have been 3 inches, as the recorded observations. I would merely say, however, that the plan being an appendage to my report, is explained by it; and the observations in it, are

stated with such precision, as well as the circumstances under which they were taken, that I see no need of there being any difficulty in the case. But if it suits your humor to make any, I have nothing more to say against it. E. S. C.

JERSEY CITY, June 17th, 1849.

E. S. CHESBROUGH—

DEAR SIR:

I have just opened your letter of 12th inst. It arrived in due course of mail, during a brief absence from home. The testimony of "highest scientific authority," which you have quoted, only proves that both yourself and the scientific authority, committed a very great error in involving velocity of stream in a formula for computing the quantity of water discharged over a weir, by the law of falling bodies. It may be some consolation to know, that the error in the Encyclopedia, has been copied word for word, by many modern writers, as well as yourself. I will give you the credit of having copied only half the error; for in your formula, you merely *add* the velocity of stream, while the Encyclopedia to which you refer, and many of its copyists, "*multiply* the opening by the velocity of the stream," and thus "increase the discharge" by a ratio much greater than by merely adding velocity of stream.

In my letter of 6th inst., I gave the physical cause for dispensing with velocity of stream in formulas for computing the quantity of water discharged over a weir, by the law of falling bodies. The error in the Encyclopedia, may mislead the novice, but the practical engineer, even if ignorant of the law of falling bodies, should see that it is a physical impossibility, and therefore a physical absurdity, to support a column of water on a weir or dam, "on a supposition that the water from which the discharge is made, is in a state of *stagnation*." The column, is water falling in space; the fall or motion of the water requires motion in other water to supply its place in the column; and hence, the column cannot exist without motion (velocity) in the stream of water that supplies it; and hence, "the evidence of observation repeated on a large [or small] and most satisfactory scale, and the testi-

mony of the highest scientific authority, both in this country and in Europe," *cannot* maintain a column of water on a weir or dam, while "the water from which the discharge is made, is in a state of *stagnation*."

Some modern writers, in copying that paragraph from the Encyclopedia, as if aware of its absurdity, stop short at the word "stream," and by leaving out all allusion to "increased discharge," the paragraph may be sensibly construed to mean, that the velocity multiplied by the opening, will equal the quantity in table, computed by the law of falling bodies. This is true,—because the "opening" is the area at that point; and the velocity multiplied by the area, at any point, is always precisely equal to the quantity passing—or, in other words, it is equal to the quantity discharged over a weir or dam; because the quantity falling over a weir, is always precisely equal to the quantity passing any point of the stream in the same space of time.

Your recorded observations of April 20th, are not well taken. From 11 hour 45 m. to 11 hour 55 m. of time, both inclusive, you record "Day's mill stopped" and "Day's mill started." The gates were never lowered and raised in so short a period of time. I was an eye-witness to your experiments of closing Day's gate-way. It raised the water full 1¼ inches, or nearer 1½ inches on dam; and the opening of gate-way, lowered the water the same amount on dam and at station A, near dam. You may assure yourself of that fact at any time. Since your survey, Mr. Day has added one wheel of same size as first: the water for one wheel will at any time lower the column on dam 1½ inches,—and starting both wheels, will lower the surface on dam, or at station A, 3 inches, nearly or quite. Your recorded observations, so far as they can be made intelligible, show that on April 19th, at 3 h. 5 m., the water at A stood 2½ inches. "Flash boards 3 inches high put on," and then at 3 h. 55 m., the water stood 4⅛ inches, showing a rise of 1⅝ inches due to flash boards. On April 20th, the same flash boards on, and wheel stopped, at 10 h. 10 m. the water stood 6 inches at A; at 11 o'clock, with flash boards removed and wheel started, the water stood at 3 inches, showing a fall of 3 inches in all—of which 1⅝ inches, as shown on 19th, (and not 3½ inches, as shown by red lines,) was due to flash boards, and 1⅜ inches was due to wheel. This is very near the truth, and as near an approximation as your "recorded observations" will allow.

You say that your "brother's measurements sustain" what you have said in regard to the dam. Now, as that is the most important,

and indeed the all-important point in this controversy, let us examine what you have said, and then we will see what measurements, what elements, or who "sustain" you. On the profile accompanying your report, you have drawn a dotted black line; at one end you have placed it 7½ inches below surface, and at dam, you have placed it 2 feet below surface of river. You there say, "the dotted black line shows estimated surface of river, would have been April 23d, had Day's dam been removed." That statement is accompanied with "elements and results of observation," and a formula used in calculating the inclination of the surface, and is signed "E.S. Chesbrough, surveyor." At your invitation, I examined and pointed out a very important error—an error that is fatal to the whole—because it is the base of all your estimated levels for removal of dam. You then, for the first time, discovered that the estimate had no base—that you never had the proper elements for such an estimate—and the whole was based on a mere guess of your own, or as you expressed it in your letter of 4th inst., you "had no doubt while at Great Barrington, that the removal of Day's dam would immediately lower the surface of water there upwards of two feet." But after I had pointed out the error, you then "have taken steps, for your own satisfaction, to have certain levels and measurements taken;" and now in your letter of 12th inst., you say, that your "brother's measurements sustain" you. Now, before your brother's measurements can sustain your statement, it will be necessary that you append those measurements to your report; and those measurements must give the width, bed and surface of the natural Housatonic, at and below dam; and then we will have the only elements that can show how high the surface of water would be, if Day's dam were removed. In giving those measurements, it will not serve the truth to "assume the river," at and below dam, "to be 100 feet wide." At the dam itself, you will find a very durable monument, the stump of a tree that was cut down by Mr. Day's mill-wright, that will show you that the natural Housatonic was *less* than 75 feet wide, before the dam was built. At 750 feet below dam, you will find that the river is now less than 71 feet wide, and at least half of that 71 feet, is entirely obstructed by rocks, that rise on an average 2 feet above a low stage of water. The measurements at these points, are indispensable elements in estimating the surface of water, if Day's dam were removed, and the river restored to its natural boundaries. If you will complete your survey by adding those measurements to your

report, then I will show by your own elements and your own formula, that if Day's dam had been removed and the river restored to its natural bounds, the surface of water would have been higher "on 23d April," than it was with dam and race-way existing. Will you complete your report by adding width, depth and height, of natural Housatonic, at and below dam, to the narrow point 750 feet or thereabouts, below dam? I wait your reply.

Yours, &c.

C. F. DURANT.

West Newton, June 21st, 1849.

Dear Sir:

Yours of the 17th was received yesterday. I am aware that some men of scientific and practical skill in hydraulics, and authorities too for which I have great respect, do not give as much effect to velocity of stream above the immediate effect of the overfall, as I have done in the formula furnished you; but not an engineer or scientific person, or author that I am aware of, professing to know anything about the subject, (save yourself,) asserts that the velocity of stream should not be taken into account, (and I mean the velocity above the curve in the surface caused by the weir) in estimating the quantity actually discharged by the weir. My reason for adopting the rule I used, was, because it conformed very nearly to the results of observations, that were satisfactory to myself, at least, and to others also. I pretend to no infallibility on this or any other subject, however,—and must confess that I have none in yours. Your scientific reasoning on this subject, is to my mind exceedingly defective; but were it ever so plausible, I can have no confidence in what contradicts facts.

Whatever may be the case with regard to the closing and opening of Day's gate, my observations are simply a record of the statements of his own men. If they were mistaken, of course I have been deceived; but I have unshaken confidence in their statements still, notwithstanding your abortive attempt to garble the observations, and your success with regard to their intelligibility.

I look upon all your assertions about proving from my elements and formula, that the water would have stood higher where Day's dam

now is, on the 23rd of April, than it actually was, if the dam had been removed, as the purest braggardism.

If Mr. Day is willing to incur the expense, I am willing to have the measurements you desire made, and appended to my report.

With due respect,

E. S. CHESBROUGH.

C. F. DURANT.

NEW YORK, June 23d, 1849.

E. S. CHESBROUGH—

DEAR SIR:

Du Buat, the great law-giver, and the fount from whence springs nearly all our correct knowledge of Hydraulics, possessed the talent and had the means at his command, and devoted as much time as any modern writer, or modern engineer, to ascertain the quantity of water discharged over a weir. He built canals, and aqueducts, and reservoirs, on a grand scale, and specially designed to ascertain the true physical laws that govern falling and running water. The result of all his labors shows, that water passing over a weir, is matter falling in space, and hence his formula for computing the quantity, is framed on the universal law of falling bodies. If Du Buat is not high and the highest scientific authority on that part of Hydrodynamics, then the science is a fiction, and you may have full "confidence in what contradicts facts," your own "results of observations."

I have full confidence in your "recorded observations," and have never expressed an adverse opinion. Whatever may have been the object in view, they are certainly not well taken to show clearly the amount of rise due to wheel, distinct from that which is due to flash boards; they indicate $1\frac{5}{8}$ inches due to flash boards, and $1\frac{3}{8}$ inches due to wheel; that is sufficiently near the truth, although the mode of taking them is not the best to show clearly the exact truth.

The measurements alluded to in my last letter, are those which you state were taken by your brother, and which in your letter of the 12th inst., you say "sustain" what you have said. In all your report you will perceive, there is not one measurement on which to base

your estimated dotted black line, for removal of dam. That being the most important part of your survey, it should not rest on mere conjecture; the width, depth and height, of the natural river, at and below the dam, are essential and indispensable elements to compute the height of water when restoring the river to its natural flow. When those measurements are appended to your report, then your own formula will show that 800 cubic feet of water per second, the amount which you have given, could not pass that point on the natural river at a less height than it stood on the 23d of April, with the artificial dam and race-way existing. If you have not leisure to make that computation yourself, and will append those measurements to your report, I will very cheerfully compute the height for you, with your own elements and your own formula. I shall be happy to hear from you.

Your letter of 21st inst., to which this is in reply, came to hand this morning.

Yours, &c.

C. F. DURANT.

West Newton, June 26th, 1849.

Dear Sir:

Your letter of the 23d was received yesterday, when I was very much pressed in getting ready to make a report to the Water Commissioners in Boston. Other engagements since, have prevented me from being as prompt as you were in answering my last.

While in the city, yesterday, I went to see a friend, and borrowed a copy of Du Buat. It is the Paris edition of 1816, in three volumes. In volumn 1, pages 197 to 203, (or, in case you should have a different edition, part 1, section 3, chapter 3,) he discusses the discharge over a weir in the side of a reservoir, with still water above them; and over one which extends entirely across a stream which has an acquired velocity before reaching the curve at the overfall, or weir. Supposing the quantity discharged, which he represents by D, to be the same in both cases; he gives the following formula for finding the value of h, the head necessary to give this discharge, (supposing l, the length of weir to be the same also in both cases.)

First case, $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}$

Second case, $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\sqrt{2g}\ (a+h)}\right)^{2}$

Showing most conclusively, that in the latter case a less actual height of column is required to discharge the same quantity, than in the former. Lest you should think I misapprehend his meaning, I will quote entire his solution of the second case: "Nommant donc a la hauteur du reversoir au dessus du fond de la rivière, l la largeur commune à la rivière et au reversoir, h la hauteur de la surface de la rivière, au dessus du reversoir, et D la dépense commune; $\frac{D}{l\,(a+h)}$ sera la vîtesse moyenne acquise avant de reverser, et $\left(\frac{D}{l\sqrt{2g}\ (a+h)}\right)^{2}$ sera la hauteur naturelle dûe à cette vîtesse: la première équation (143) donne $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}$ QUAND L'EAU D'AMONT EST EN REPOS: ainsi AVEC UNE VÎTESSE ACQUISE, on aura

$$h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\sqrt{2g}\ (a+h)}\right)^{2}\text{"}$$

The double underscoring, if you compare the extract with the original, you will see is mine. Thus, according to your own acknowledged standard, the velocity of stream above a weir, in estimating the quantity discharged by the weir, *must be taken into account;* and in order to get that velocity you must know the depth of the stream above the weir. Hence, it is a great mistake, to say that in such a case, it matters not whether the depth is 5 or 5000 feet.

With regard to the observations that were made on the effect of opening and shutting Day's gate-way, I am very much gratified to find you have confidence in them, notwithstanding you think they were not recorded in the best or clearest manner; for I drew a very different inference from your previous letter; and would beg your pardon for accusing you of intentionally garbling them.

Now let me ask, why you reject experiments that were directly made to ascertain the effect of closing and opening Day's gate, made too, in the only way that I can conceive of, to ascertain the truth satisfactorily; and make use of other experiments, made on different days, and in different stages of the river? You object to the statement, that the gate was

opened and closed in the short space between 11 50 A. M., and 12 M., April 20th. I can see no force to the objection; but for argument's sake, I'll admit, that the observations then made, prove nothing of themselves. But what is your objection to the observations made between 10 30 and 10 40, A. M., the same day? They give precisely the same result as the others. What is your objection to those taken between 8 35 and 8 50 A. M., the same day? They give a result differing but $\frac{1}{8}$ inch from the others, and most probably this difference was owing to a slight wave passing, when one of the observations was taken. You speak of the flash boards and closing of gate, raising the water three inches, on the 19th of April; but you have no evidence that it did, or would have done so. Mr. Emerson's observations, of May 21, when the river was in very nearly the same state that it was April 19, shew that the flash boards and closed gate raised the water at A, but $2\frac{1}{4}$ inches. The fact that the gate was closed, is not mentioned in the record; but Mr. Emerson distinctly stated it in a letter to me, dated May 28th. Now if $2\frac{1}{4}$, or even $2\frac{3}{8}$ inches, be allowed as the effect both boards and gate would have had, on the 19th of April, then by deducting the portion you attribute to flash boards, ($1\frac{5}{8}$ inches) there will be left just the same result as in the other cases. You will perhaps say, why then was the water raised three inches, May 20th? My answer is, the river was considerably, or at least materially higher,—and the boards might have been placed somewhat differently, so as to produce part of the effect. At all events, I cannot see the propriety of rejecting the plain results of four experiments, three of them agreeing precisely, and the other differing from them very slightly, when those experiments were made with direct reference to ascertaining the truth; and afterwards adopting a doubtful inference, obtained by combining other experiments in a very uncertain way.

The result of my brother's levels, shews a fall in the surface of the water at Day's dam of 23 inches. I assumed in my report that it was 24 inches, and the profile represents it as still more; but the 24 inches is what I based my calculations upon, and do not conceive an error of an inch at the dam, would affect the result at the B. W. Co's. wheel over a quarter of an inch, (a matter of no practical importance.) The widths of the stream near the dam are on the plan; but I have had no widths or depths of water below the dam taken, not thinking it necessary; for the fact that the water runs off now below the dam, with the present depth, is sufficient evidence to prove that

it would run off at the same depth, if Day's dam were removed. Indeed, I cannot conceive, why the removal of this dam should raise the surface of the water below it (after a few hours) in the least; on the contrary, I think there would be a very slight effect the other way.

If, however, you think the widths and depths of the river for 750 feet below the dam ought to be taken, and would enable you to prove that I am entirely wrong in my conclusions, I am very willing to have it done at Mr. Day's expense—(I don't think it would exceed $20 or $25;) and would thank you to say so to him. I should like, at the same time, to have the surface of the water between his dam and the B. W. Co's, levelled over again, in *a low stage* of the river, so as to compare with my theory.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. Durant, Esq.

P. S. As mentioned in my last, I do not mean to claim for my formula for calculating the discharge by weirs, perfect accuracy, or universal application; for in most cases it probably gives too much; but as you must see, Du Buat himself goes against your theory most decidedly.

Jersey City, June 28th, 1849.

E. S. Chesbrough—

Dear Sir:

Your letter of 26th is at hand. The measurements for 750 feet below the dam, are important and indispensable elements to form a base for your estimated "dotted line," for "height of water on 23rd April, had Day's dam been removed." Without those elements, your statements in regard to "dotted black line," if dam was removed, are mere conjecture; a conjecture on the most important point, and on the base of all your estimates for removal of dam. If you desire those measurements, the widths, depths, and heights of the natural river below dam, I have no doubt Mr. Day will aid you in taking them, if you

address him on the subject, at Newport, R. I., where he is sojourning for a few days. Your brother's measurements, it appears, do *not* "sustain" what you have said in regard to the dam; he found a fall of only 23 inches in the surface of water at Day's dam, and that with a dam of 112 feet long, where you assumed the removal of the dam, would lower the surface 2 feet; that is an error of 1 inch, and that is a very small integral part of the error, as you will perceive, if you will apply Du Buat's laws to show the height of 800 cubic feet of water per second, passing in a stream 112 feet wide, compared with the height at which the same quantity would stand when flowing over the same declivity of bed in a channel less than 75 feet wide. By the same laws, you will find that the narrow channel 750 feet below dam, will at every change of flood, change the relative heights above and below at dam. That which your brother found 23 inches, would be less in a greater flood, as at the time of your survey; and that which gave your brother 23 inches, would, in great floods, even with the dam of 112 feet existing, be reduced to nothing, or in other words, the entire fall will be destroyed, and the water will pass that point with a uniform declivity in the upper surface. Du Buat's laws lead to this result in all dams that have a narrower channel below; and Day's dam at Great Barrington, will show you a practical illustration of this truth, at every spring freshet.

The quotation from Du Buat, does *not* "multiply the opening by the velocity, to increase the discharge;" and he does *not* increase the quantity by adding velocity, as you have done in $\frac{Q}{L}=H\left(a\sqrt{2gH}+V'\right)$ where a is 0.4; and he does *not* say that "the velocity of the stream above the weir, must be taken into account," in estimating the quantity, where the height and length are known.

In reasoning from first principles, he gives "*a*, la hauteur du reversoir au dessus du fond de la rivière, *l*, largeur commune à la rivière et au reversoir, *h*, la hauteur de la surface de la rivière, au dessus du reversoir, et D, la dépense commune." Then "$\frac{D}{l\,(a+h)}$ sera la vîtesse moyenne acquise avant de reverser, et $\left(\frac{D}{l\sqrt{2g}\;(a+h)}\right)^2$ sera la hauteur naturelle dûe à cette vîtesse." That is very clear: the velocity (*vîtesse*) is equal to the quantity divided by area; $a+h$ equal depth, which multiplied by l, the length, equal area of the

river; and $\left(\frac{D}{l\sqrt{2g}\,(a+h)}\right)^2$ will be the *natural height due to this velocity.*

The first equation (143) gives "$h=\left(\frac{D}{0.431\,l\,\sqrt{2G}}\right)^{\frac{2}{3}}$ quand l'eau d'amont est en repos: ainsi avec une vîtesse acquise, on aura $h=\left(\frac{D}{0.431\,l\,\sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\sqrt{2g}\,(a+h)}\right)^2$" That is also very clear: at the instant of opening the column, when the water above is in repose, $h=\left(\frac{D}{0.431\,l\,\sqrt{2G}}\right)^{\frac{2}{3}}$; but this could not exist in practice, because such a column could not be maintained without a motion in the water that supplies it, and that motion or velocity, will of itself create a column, or $h=\left(\frac{D}{l\sqrt{2g}\,(a+h)}\right)^2$; and as the actual discharge is due *not* to the velocity of stream, and *not* to the water above being in repose, but to the law of falling matter,—hence the actual height, or $h=\left(\frac{D}{0.431\,l\,\sqrt{2G}}\right)^{\frac{2}{3}}$ less $\left(\frac{D}{l\sqrt{2g}\,(a+h)}\right)^2$; so that in estimating the quantity of water discharged over a weir, by the law of falling bodies, the velocity of the stream above the weir, *must be left out of the account;* it must *not* be multiplied by any sum *to increase* the discharge, and it must *not be added* to any sum to increase the discharge—as the Encyclopedia and your formula have it; but it must be left entirely out of the account: and, as the depth $a+h$, is involved in the velocity $\frac{D}{l\,(a+h)}$; and the height due to velocity, is subtracted from and left out of the account—hence, whether the depth be 5 or 5000 feet, it *cannot* increase or diminish the height of column on weir, required by the law of falling bodies, to pass the same quantity on the same length of weir.

Your words, "supposing the quantity discharged, which he represents by D, to be the same in both cases," show clearly that you do not understand the meaning of Du Buat; because, the first case (143) discusses a column *dûe quand l'eau d'amont est en repos*, or when the quantity is infinite, so as to maintain a column without velocity in the stream; and as the quantity passing in a river, is always limited, hence the height h required to pass that limited quantity, is

$$=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\sqrt{2g}\ (a+h)}\right)^{2};$$

because the first $\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}=h$, would discharge a quantity due to an infinite and instant supply, which cannot exist where the supply is limited, and requiring velocity to furnish the supply.

Your "recorded observations" on opening and closing gateway, *are* recorded in a satisfactory manner. It is the mode of taking them, and the results or inferences which you draw, that are exceptionable, and in answer to your interrogatories on those points, I beg to say—the time from 11 40 to 11 50, ten minutes, with only one observation of height in that interval, is not sufficient time to show the rise, or to show the beginning and end of closing gateway, as from the construction of the gates, they require several minutes of time to open or to close. From 10 30 to 10 40, on the same day, the wheel is started in too short a space of time after removal of flash boards, to show clearly the amount of fall due to flash boards; it required 10 or 15 minutes to remove flash boards; and you neither record the beginning, progress, or end of that operation, or allow sufficient time to show effect of boards before wheel is started. From 8 35 to 8 50, or to 9 25, the recorded observations show no change at A or B, in stopping wheel, and therefore that is clearly a mistake; you must have an erroneous copy of your report, if "they give a result differing but ⅛ inch from the others." In my letter of 17th inst., I gave you my "evidence"—your own "recorded observations," that the removal of flash boards and closing of gate, lowered the water 3 inches. To that evidence, I will add, that I was an eye witness, and measured it. I will also add, that the flash boards were 3¼ inches high, and by Du Buat's laws, when gate-way is closed, 3¼ inch boards will raise the water 3¼ inches on dam, at any time. The laws are universal, and you may satisfy yourself of that point at any time, by a practical demonstration on any dam.

Mr. Emerson's observations on 21st May, were, I presume, taken under your direction; between 1 30 and 3 30, an interval of two hours, the flash boards are put on, but not one measurement is taken to show whether the river has fallen or raised, in that long interval of time; surely that mode of taking observations, cannot indicate the amount

of rise due to flood, to flash boards, or to wheel. I shall be happy to hear from you.

Yours, &c.

C. F. DURANT.

West Newton, July 2d, 1849.

Dear Sir:

Yours of the 28th ult., was received this morning; and I have already written to Mr. Day, directing to Newport, R. I.

With regard to the quantity of water discharged by weirs, I will begin, by stating, that I believe my own formula, as well as the rule laid down in the Encyclopedia, to be incorrect, so that these need not enter into any discussion we may have on the subject hereafter. I differ very much from you, however, in your interpretation of Du Buat, and can hardly persuade myself that you have read in the original, all that he says on the subject. If he considered $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}$ a merely theoretical rule, not applicable in practice, why did he—see page 200—(143) give a tabular statement of actual discharges, and compare them with the theoretical, as computed by this same formula, (D and h being transposed)?

In your reasoning about the depth of stream above weir, being of no account—that is, whether it is 5 or 5000 feet—you very strangely admit that Du Buat does involve it in velocity, and then say that it is left out of the account. As you observed, the depth $a+h$ is involved in the formula $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\ \sqrt{2g}\ (a+h)}\right)^{2}$

Now to my mind, it is a perfect contradiction to give such a rule, or rather admit it to be conclusive, and then say it matters not what the value of a is. How can you find the value of h without knowing that of a? Certainly if Du Buat is to be taken as authority, you cannot. You must either set aside his formula, or you must take the depth above the weir into account.

With regard to the observations taken by Mr. Emerson, I regret very much, in consequence of the doubt you have as to their utility,

that he was so long in getting his flash boards arranged. It is possible, that while he was arranging them, the river might have fallen; but that from 12 to 1 30 A. M., previous to putting on the flash boards, and from 3 30 to 4 40, A. M., after they were on, there was no change in the river, is very evident from the observations themselves; and it is exceedingly improbable that any change took place between 1 30 and 3 30.

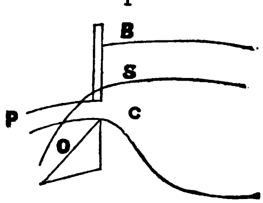
It is very easy to object to the manner in which the observations were made; but if you will be kind enough to suggest a better mode, I will endeavor to have another trial made, in case Mr. Day should direct anything further done.

From 8 30 to 8 50, A. M., April 20th, the "recorded observations" shew a change at A, of $\frac{5}{8}$ of an inch, and at B, of $\frac{1}{4}$. The flash boards were removed entirely, between 10 15 and 10 20, A. M., as the manner of recording the observation, with a bracket,

(thus, 10 15 ——————— } flash boards
10 20 ——————— } removed,)

was intended to shew. The original notes state expressly that the last board was removed at 10 20.

I *have* made some experiments and observations on dams, but do not find that the surface of the water is always raised or depressed as much as the dam is raised. The difference, it is true, is in most cases very small; but there is a difference, Du Buat himself being the judge. According to Du Buat, if you raise a tight dam, other things remaining the same, it is necessary to *increase* h a little, to pass the same quantity of water. In our experiments, however, there was a special reason why the flash boards should not have raised the surface of the water a height equal to their own. It is because they did not fit the top of the dam, but left in many places considerable openings for the water to escape underneath them. Now it is very evident



that in such a case, by leaving an opening, as at C, below the board, you may raise the surface from S to B, till the head shall be sufficient to discharge all the water through C towards P, instead of towards O. No additional height above B, of flash board, could raise the surface of the water. It is true, that such a case would be an ex-

treme one; but it shews that an equal height of flash board, does not necessarily cause an equal elevation of the surface of the water; unless they fit close to the top of the dam. The whole object of the flash boards, was to raise the water at A an appreciable amount, and then to let us observe the effect of the "remove," as Du Buat calls it, higher up the stream. As you are aware, the top of the dam is quite irregular, and it was therefore impossible, had it been thought desirable, to make the flash boards fit close to it.

I agree with you, that the greater the flood on the Housatonic, the less will be the relative difference of levels between the surfaces of water above and below Day's dam. This would be the the case to a certain extent, if there were no contraction below, in the width of the stream.

I am unable to see, however, what effect this is to have on the height of my dotted black lines. They were calculated on the supposition that the state of the river was to be, as it was actually found, by observation, on the 23d of April; that is, the actual height of water then observed, with the quantity actually passing at the time. If the quantity be estimated by Du Buat's formula, it will be less than I have stated it in the report; but strange to say, a diminution or increase of the quantity passing, per second, has no effect in changing the computed heights at the different stations, of the dotted black line. The reason, however, is obvious. In the formula used, $I = \frac{Q^2 p}{a D^3 W^3}$, p represents the value of fiction for the quantity passing, when the observation was made, and for the actual inclination of the stream. Now it is very evident, that if I, $\left(\text{in } I = \frac{Q^2 p}{a D^3 W^3}\right)$ be fixed, as it is by observation, and $a\ D^3\ W^3$ be also fixed, $Q^2 p$ must be a constant quantity; consequently if Q be diminished, p will be increased, or vice versa. The value of $Q^2 p$ being thus fixed, the formula was afterwards used to find the value of I, when D varied. It was the knowledge of this, that made me less careful about the precise quantity passing per second, than I should otherwise have been. Indeed, some of my first calculations were based upon the quantity, as derived from the old and simple formula, used in the construction of Du Buat's tables that you mention; at least, the quantities you take from that table, agree with the formula that I have always used for common cases. The result of some observations made here, (on a much larger scale than

Du Buat reports his own experiments to have been) and a rule laid down by Gregory, in his mathematics, led me to the adoption of the formula I sent you $\left(\frac{Q}{L}=H\left(a\sqrt{2g\,h}+V'\right)\right)$, which I am willing to abandon.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. Durant.

Jersey City, 5th July, 1849.

E. S. Chesbrough—

Dear Sir :

The English professor, Dr. Gregory, to whom you refer, does not take into account, the velocity of stream, in his formula $Q=11\frac{1}{2}\ l\ H^{\frac{3}{2}}+(n+\frac{1}{20}n)$ times the quantity for 1 inch in length. In referring to Dr. Robison's table, computed from Du Buat, he falls into the same error by using nearly the precise words from the Encyclopedia.

In Du Buat, $a+h$, is left out of the practical discharge; or *subtracted* from the height due to an infinite and instant supply, by the statement $h=\left(\frac{D}{0.431\ l\ \sqrt{2G}}\right)^{\frac{2}{3}}-\left(\frac{D}{l\sqrt{2g\ (a+h)}}\right)^{2}$. The value of h, is always the first and most readily known by measurement, and in practice, the values of h, and l, are generally obtained by measurement.

Boards that reach to, or above the surface, cannot be called flash boards. Water flowing beneath them, must be governed by the general law for discharge from beneath the surface. Flash boards, which by imperfectly fitting dam, allow a portion to escape below, must notwithstanding, raise the surface nearly equal to width of boards; because, although the quantity escaping below, is increased by the pressure, the diminished height of column above, has lost its power to discharge in the same ratio by the law of falling matter.

I think no good can result from our discussing the probabilities of rise or fall in flood, at the time of Mr. Emerson's observations; and indeed, all the preceding matters relating to discharge over a weir, although interesting in themselves, they cannot aid us in coming to an agreement on the height of your "dotted black line," if dam was removed and the water restored to its original channel.

It is *not* "strange that a diminution or increase of the quantity passing per second, has no effect in changing the computed heights at the different stations of the dotted black line." But it is very strange, that when you discovered that your formula $I = \frac{Q^2 p}{8744 D^3 W^3}$, would so distort the physical truths, that you did not instantly abandon it, and discard it on account of its physical absurdities. Where $Q^2 p$ must be a constant quantity, and made constant by increasing the value of p, as that of Q^2 is diminished, was enough to make you, without reflection, "less careful about the precise quantity passing per second;" because in such a case, *quantity* and *area*, those important items that form the base of all Du Buat's laws, and the base and substance of the whole science of hydraulics, are in your formula, assuming fictitious values as changing co-efficients, to distort the physical truths. I did hope, that in calling your attention to the error of placing the dotted black line, too low at dam, and by pointing out the absence of any base to start it on, that you yourself would see the unsoundness of your formula, when you should attempt to compute the height of 800 cubic feet per second, passing at dam, in a channel less than 75 feet wide. I know that you have the ability, and I judged, that when you leisurely viewed the effect of your formula in such a practical operation, you would correct your own error by discarding the unnatural and distorted combination that produced it. I desire to hear from you on this point. Your letter of 2nd inst. was received this morning.

Yours, &c.

C. F. DURANT.

West Newton, July 10th, 1849.

Dear Sir:

I have time to say but a few words this morning in reply to yours of the 5th, which was not received till yesterday—a busy day as well as night—with me.

I have not yet, even with your hints, discovered that *my formula distorts* the truth. This, however, may be owing to my ignorance; and as soon as I can see an error in it, I shall acknowledge it. With regard to the actual state of river at the dam before it was built, of course, I could not tell, without tearing up the dam. What it is immediately above, I do know, from actual measurement, and think I have enough, from actual observation, of its state below the dam, to justify the application of my formula. Now, it would shorten our discussion of this matter, if you would point out definitely, where my formula is wrong; or, if you prefer it, give me one that is right, by stating it in such clear terms that I cannot mistake it. At the same time, you would favor me by letting me know, for what distance at the dam the river would be only 75 feet wide, if the dam were removed.

In haste,

Yours, &c.,

E. S. CHESBROUGH.

C. F. Durant, Esq.

New York, July 13th, 1849.

E. S. Chesbrough—

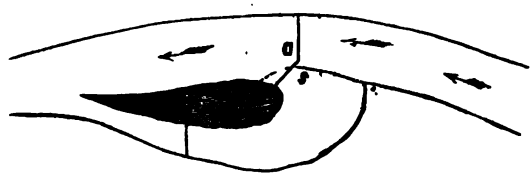
Dear Sir:

Your letter of the 10th inst., is at hand.

It is clearly wrong in any formula for computing inclination in running water, to give fictitious values to perimeter. The perimeter of a river must always be the bottom and sides, neither more or less; and when the river is assumed at 100 feet wide, with depth from 2 to 5 feet, the perimeter must never be less than 104, and never more than 110 feet; the laws require strict compliance to this rule. Your formula in the above case, make perimeter from 82 to 1776 feet.

The resistance or friction, is as the square of the velocity, and when rocks, or piers, or narrowed sides obstruct the channel, then V^2 must have an increased force, by increasing the radius of Du Buat $= \frac{a}{p}$ above, and thus increasing the inclination below.

The original 75 feet width of channel at dam, I think, would not exceed twenty or thirty feet in distance. The stump that marks the point, or bend of original river, lies nearly in a line with the westerly side of dam, thus,—



S, the stump, I found, by measurement, to be $74\frac{8}{12}$ feet distant from westerly side of river. As I never saw the locality until the dam was built, I cannot give a precise diagram of the original channel at that point. The dotted line is merely conjectural, from descriptions given by a number of gentlemen at Great Barrington.

It is very warm here to day; Fahrenheit ranging near 96°. Let me hear from you at your leisure.

Yours, &c.,

C. F. DURANT.

West Newton, July 17, 1849.

Dear Sir:

Yours of the 13th inst., was received yesterday morning, and I have, during leisure moments, thought a good deal about its contents. It seems to me, that your positions are not altogether tenable; at all events, I'll give you my reasons for differing from you. You say, that "it is clearly wrong, in any formula for computing inclination in running water, to give fictitious values to perimeter. The perimeter of a river must always be the bottom and sides, neither more nor less." So far, I am willing to admit what you say, the difficulty being, in practice, to measure the actual length of surface on bottom and sides

in contact with water. But you go on to state, that " when the river is assumed at 100 feet wide, with depth from 2 to 5 feet, the perimeter must never be less than 104, and never more than 110 feet; the laws require strict compliance with this rule." Now, suppose the bed of a river to be perfectly smooth, and to have a semicircular form. How would you estimate the perimeter? It strikes me that *you* would not hesitate to call it equal to half the circumference of a circle, of which the width of the stream would be the diameter. Suppose, however, the bed of a river to be made up of several semicircles, with the top of the water just above their centres; would you not call the whole perimeter equal to the perimeters of all the semicircles? Some contend, that the contour of every leaf cut by the section of the river, should be taken into account when estimating the perimeter. But, suppose we lay all this aside, and call the perimeter just equal to the width of the stream added to twice its depth. What then? Does it alter the result of my formula? Let us see.

You say, the resistance is as the square of the velocity. That is true (or very nearly so,) and of course you will not doubt that your own formula $I=\frac{V^2}{12000R}$ is general in its application, especially, if you give it the form $I=\frac{V^2}{aR}$, and find a value for a to suit the conditions of each case. This formula certainly makes I, (which is a measure of the resistance, being the inclination necessary to overcome it) dependent upon the square of the velocity, and increases with it.

Now, my formula is nothing more than yours actually developed. V^2, in yours, is obtained by dividing the quantity per second by the area of the water section, and squaring the quotient; or, as I have expressed it, $V^2=\frac{Q^2}{D^2\ W^2}$, D being the depth, and W the width of the stream. R, in yours, $=\frac{a}{p}$ of Du Buat; or, as I have expressed it, $\frac{D\ W}{W+2D}$. Substituting these values, your formula would become

$$I=\frac{\frac{Q^2}{D^2\ W^2}}{a\frac{D\ W}{W+2D}}=\frac{Q^2\ (W+2D)}{a\ D^3\ W^3}\ ;\ \text{but } W+2D=p,\ \text{hence, } I=\frac{Q^2\,p}{aD^3\ W^3},$$

which, for convenience, we shall turn into the form $\frac{Q^2}{D^3\ W^3}\times\frac{p}{a}=I.$

Now, it is very evident, that so long as Q, D, W and I have been obtained by actual measurement, and for each case may be considered as constants, $\frac{p}{a}$ must vary, in order to fill out the equation. If you diminish p, you must diminish a by the same multiple. There is a slight error *mentioned in my report*, in the application of this formula to the Housatonic. In lowering the surface of the water, of course p would be somewhat diminished, but in no case quite as much as four per cent., and generally less than three.

It has occurred to me, you may possibly think that the practical coefficient $\frac{1}{a}$ after having been ascertained as above, for one depth of stream, ought, when used for another, with the same quantity passing, to be varied according to the square of the velocity. Do you think so? Please let me know at your earliest convenience; as I intend, as soon as we can agree upon a formula, and the elements, to go over my calculations, by which the dotted black line was established.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. Durant, Esq.

Jersey City, July 20th, 1849.

E. S. Chesbrough—

Dear Sir:

Your letter of 17th inst. is at hand. If the bed of the river is a semi-circle, then it would be correct to make the half circle, the precise perimeter; because, if the width of river equal the diameter of circle, equal 100 feet, then the area is$=100^2\times.7854\times.5=3927$ feet; and perimeter is$=100\times3.1416\times.5=157.08$; and the mean radius of Du Buat is$=\frac{a}{p},=3927\div157.08,=25$ feet. That is precisely what was intended by the author; and as you will perceive, it fulfills all the requirements of the law,—because the friction, although as V^2, must vary as the whole quantity of water inversely, or as R. This will be very apparent, when we reflect on the analysis of R, and on its func-

ion in the formula $I=\left(\frac{V^2}{R}\right)\div d$, where d, the distance, which I will presently discuss, bears a mean proportion in V^2 and R.

The radius of Du Buat is a perpendicular raised on the entire line of perimeter, or, in other words, the two lines show a rectangle that holds the entire weight of water in the section; for example, in the preceding case, a river bed, the half of a circle of 100 feet diameter, the radius 25×157.08 the perimeter, $=3927$ feet, the entire quantity of water in the section.

The effect of fictitious values to perimeter may be seen by the operation of your formula, $I=\frac{Q^2 p}{8744\ D^3\ W^3}$. Take, for example, sections 2 to 3, distance 100 feet, average depth 4 feet, estimated perimeter 1268; then with the assumed values, $I=.00145$, or for 100 feet, .145, not .154, as stated; and with the true value of $p,=108$, and the other values as assumed, $I=.000123$ for unity, or .0123 for 100 feet; being only about one-twelfth part of that which results from the fictitious 1268 perimeter.

With correct values to all other symbols in your formula, I see no objection to the coefficient $a=8744$; the difficulty lies in turning perimeter into a mere coefficient. From the mode of ascertaining the value of the coefficient p in your formula, Q, a, D, and W, are of no importance; however much they violate the truth, p will balance I, because its value is fixed solely by adapting it to the known value of I, and to the assumed values of all the other symbols in the formula.

For that estimate, Q is the only symbol with a correct value; W, on the Housatonic, varies 35 per cent. frequently in a distance of 20 or 50 feet; D varies very abruptly, and so sudden are all these variations on that part of the Housatonic, that we cannot obtain correct values by equations in the formula from the value of I, unless its values are obtained to near unity, or to 5 or 10 feet distances by actual measurement; a process exceedingly tedious, and involving a yet more tedious and complicate calculation to arrive at the object in view.

A careful consideration of the laws, shows two ways of obtaining the information sought for, without the danger of error always attendant on complicate calculations, and without requiring that intense application of mind, which, while it nourishes the mental, at the same time enervates the physical system, at a time like the present, when

HE, who made all laws, is for some wise purpose, desolating the land by some unseen messenger of death; and thus far, the only information HE has vouchsafed to us on that matter, is to preserve our physical energies to the utmost of our abilities.

First,—the dam of 112 feet added to raceway for the two wheels 20 feet more, making in all a dam equal to 132 feet long for the discharge of water; rejecting fractions, a dam 132 feet long, requires a 17 inch column to discharge 800 cubic feet of water per second; now, if the river is restored to natural width, with dam remaining, then a dam 75 feet long, requires a column 26 inches high to discharge the same quantity in the same time; that gives a rise of 9 inches, and that over a perpendicular dam with a velocity of about 5 per second, viz.: $75 \times 2.166 = 162$ feet, and $800 \div 162 = 5$, or thereabouts. Now, in removing dam, you must lower the surface 9 inches to reduce it to its actual height on 23d April, and it remains to ascertain from I, R, and V, as they would then exist, whether you could lower the surface 9 inches,—I think not, and if not, then the surface would stand as high, or higher, at Day's dam in the natural channel on 23d April, than it did with dam and raceway existing.

Second,—in a very low stage of water, Day's dam affects the surface to the lower end of B. W. Co's tail race, but leaves the water clear below the first wheel above. By the laws, the dam can influence the surface at the lower end of B. W. Co.'s tail race, only by increasing the value of R, and thus making I for *n* feet next to dam, less than I for *n* feet next to lower end of B. W. Co.'s tail race; now, so long in any stage of flood, and so far as the same relative value exists of I for *n* feet next to dam, and I for *n* feet next to *any* point above dam, then the dam may influence the surface to the furthermost point where the same relative values of I, near dam, and I, distant from dam exists; but, whenever, in any stage of flood, and to any point those relative values are reversed, then the dam has ceased to influence the surface at that remote point, and I shows that at some intermediate point or points, R has been augmented by a natural dam of rocks or narrowed sides, to a degree superior to the dam, and hence, all influence from the dam at that point has ceased.

In your survey, the quarter section next to dam, gave $I = 2.28$ inches, while the four sections entire to first wheel above, gave $5\frac{1}{4}$ inches; showing that at some intermediate point an increased R, or natural dam of rocks or narrowed sides, was then superior to Day's

dam in affecting the surface at first wheel above. The coefficien 8744 is sufficiently accurate. From its position in the formula, it represents the mean proportional between V^2 and R, or the distance on a plane in which the entire fall will $=\frac{V^2}{R}$; and whether expressed $I=\frac{V^2}{8744\,R}$, or $I=\left(\frac{V^2}{R}\right)\div 8744$, it is the same. The accuracy of the coefficient hence depends on the precision or mode of ascertaining the value of $R=\frac{a}{p}$, of $V=\frac{Q}{a}$ and of $a=D\times W$, and indeed, of Q, p, D, and W, themselves. Your position as chief Engineer of Boston and Cochituate aqueduct, will enable you to say how near 8744 conforms to accurate standard measures, with masonry as even and skilfully laid as men in the middle of the nineteenth century can perform.

My own very limited practice leads me to adopt 12000 for my mode of measuring rivers; that is, not to take into account the small sinuosities that would increase the value of W, without increasing the value of a; because, water does not flow in those sinuosities or indentations, or, if it flows at all, it flows up stream by what we call "eddies."

By leaving out of account those indentations, it is very evident that we produce a line of waterway much smoother than man with all his skill can produce with bricks and mortar; and hence, the inclination due to $\frac{V^2}{R}$, should be extended beyond the distance required for rough masonry.

From the mode generally adopted by most men in measuring rivers, probably 10000 would be the best coefficient, and I do not hesitate to recommend it generally in $I=\frac{V^2}{10000\,R}$, or $I=\left(\frac{V^2}{R}\right)\div 10000$, or $I=\left(\frac{V^2}{2\,R}\right)\div 5000$, whichever is most convenient. But in all cases, the law requires correct values to all the symbols in $\frac{a}{p}=R$.

I desire to hear from you.

Yours, &c.

C. F. DURANT.

West Newton, July 27th, 1849.

Dear Sir:

Yours of the 20th was received three days ago, but, in consequence of having to attend as a witness at court, and other matters, I have not felt like answering it; even now, I must be very brief.

You point out the effect of fictitious perimeter, by giving an example from my tabular statement of elements and results of calculation. You take the portion of the river between stations 2 and 3, and begin by saying, that the "*assumed* value of I=.145 for 100 feet," and "not 154 as stated." Now, by what means you make this correction, I am at a loss to know: .154 is right according to my manuscript copy, and is correct according to my brother's level notes, the

height of 2, above base, being		1.042
and of 3 " " "		1.196
	Difference,	.154

Instead of .154 being merely the *assumed* value of I, between 2 and 3, it was the actual value, from carefully made and thoroughly tested levels. Hence, you will see the violence done to truth and nature, by your proposed change in the formula, or rather numerical substitutes for the symbols *p*, without making any corresponding change for *a*. The formula thus used, gives but about $\frac{1}{12}$th of the *known* truth. Now, I have not the slightest objection, if you prefer it, to fixing *p* at W+2 D in all cases, if you alter the value of *a*, to correspond with the known value of I in each case,

The experience on the Croton, as well as on the Cochituate aqueduct, shows the value of *a* for smooth brick masonry, to be very nearly 13,000.

Your theory, that when the indentations of a river channel are filled up, the water has a better rubbing surface, than the hand of man could possibly form, and consequently has less friction, is very plausible, and for the simplicity of science, I could wish it true; but facts, stubborn facts, known even to the ancient Romans, prove that it is not true.

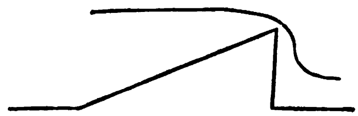
If your theory be true, why will a dam or weir shaped like No. 1, discharge more water, than one like No. 2, all other things being equal?

Why will a pipe shaped like No. 3, that is perfectly uniform in size, discharge more than one like No. 4, which is nowhere less in size than No. 3, with the same head?

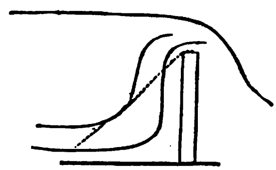
Why does the well known ajutage, as in No. 5, discharge more water, than the same orifice could, without the ajutage, as in No. 6?

If your theory be correct, all the water has to do, is to follow something like the dotted lines in Nos. 2, 4 and 6:—but actual observation shows that it follows different directions, indicated by the full lines.

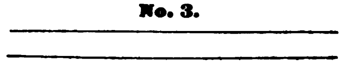
No. 1.



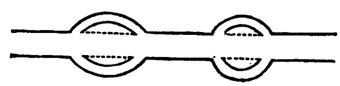
No. 2.



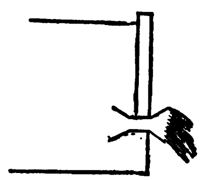
No. 3.



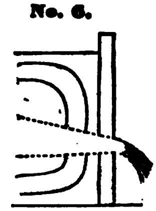
No. 4.



No. 5.



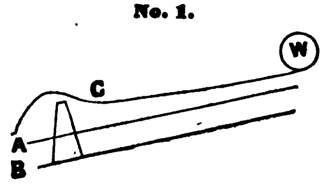
No. 6.



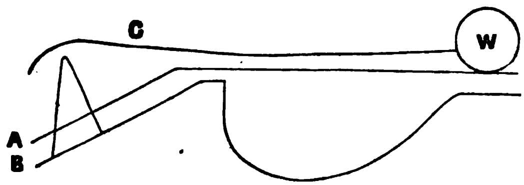
Your mode of getting at what the velocity would be at the dam, for a given quantity of water in case the dam were removed, is not stated with sufficient definiteness to enable me to examine it.

Your reasoning with regard to relative inclinations of the surface, near the dam and near the first wheel above, is very inconclusive,—as it regards the question of flowage. It is not necessary that I for *n* feet at W, should be less than I for *n* feet at C, in order to prove that the dam ceases to affect the depth of the stream; as for instance, in a case like No. 1. On the other hand, I in *n* feet at W *may be less* than at C, and yet the dam have quite an effect on the depth of the stream at W, as in a case like that represented by No. 2.

No. 1.



No. 2.



I am at a loss to know why you call *a*, a mean proportional between V^2 and R, for these are continually changing, while you propose to make *a* constant. Besides, V^2 on the Housatonic is often only about 4, while R is about 5. A mean proportional between these is certainly less than 5; but you propose to call *a* 10,000.

I agree with you that our Great Creator teaches us that we should be careful of our health, especially in these cholera times.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. Durant, Esq.

Jersey City, July 30th, 1849.

E. S. Chesbrough—

Dear Sir:

Your letter of 27th inst. is received. In pointing out the effect of fictitious values to perimeter, I did *not* say that the "*assumed value of I*=.145." I said, with the assumed values, I=.145. I never doubted that yourself and your brother, measured the levels very accurately; it was a very simple manipulation, and I have no doubt it was correctly done and that you found .154 between stations 2 and 3. Your error, or the violence done to truth and nature, originated in turning perimeter into an accommodating coefficient, "by substituting for I in the equation, its known value from observation." If you try that equation again, you will find that in all those fictitious values, you did not distort *p* quite enough to make it balance the *known* value of I between sections 2 and 3; for surely, by your own formula and your own elements there given, $\left(\frac{800^2 \times 1268}{8744 \times 4^3 \times 100^3}\right) \times 100 = .145$, and not .154 as there stated.

Your formula gives only about $\frac{1}{12}$ part of the "*known*" truth when used with a correct perimeter, because the other values are distorted in that proportion. Even the levels when correctly given for 100 feet together, cannot represent I for 100 feet, because from the very variable depth and width of that part of the Housatonic, frequently more than one half of the whole sum due to any 100 feet, will be found in one-fifth part of that 100 feet.

By leaving out of account the sinuosities or indentations, in taking the width of a river, we make a *line of waterway* much smoother; that is, *more even* to the touch, to the eye, and to the imagination, than man can or ever has produced with masonry; and it is *not* true, that the "Romans," ancient or modern, or any man or men in any age, have given one fact or "stubborn facts" to prove the contrary. "A better rubbing surface," exists only in your imagination; I certainly used no such words. I was discussing *a line*. The friction or resistance of water on a plane, is clearly laid down in the laws; directly as V^2 and inversely as the entire weight in the section, represented by radius of Du Buat. The coefficient that represents the distance on a plane in which the entire declivity will $= \frac{V^2}{R}$, is necessarily constant, so as to give the precise amount of inclination due to any change in V and in R.

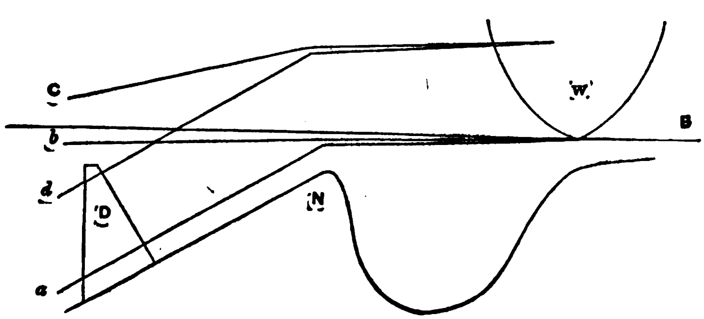
In dams that extend across a river, it is *not* true, that one shape or form will discharge more water than another. The quantity of water discharged by *any* dam across a river, is neither more or less than the precise same quantity that is passing *any* section of the river in the same space of time. The form for *openings* or *ajutages* for water, is best explained by the laws that govern the *Vena contracta*, a very interesting subject, but not particularly required in the matter we are discussing.

Your statement that "the *experience* on the Cochituate aqueduct," shows the value of the coefficient, which you call a (?) in your formula $\frac{Q^2 p}{8744\ D^3\ W^3}$, for smooth brick masonry to be very nearly 13000, opens a matter of some collateral bearing in this discussion. When at Great Barrington, I understood you to say, that experiments on the flow of water in the Cochituate aqueduct, show that you made an erroneous estimate in the required declivity, and that experience proved a declivity of two inches per mile, would have furnished the full quantity of water that was estimated to require a declivity of three inches per

mile. This result of experience in the flow, shows that the error in construction, originated from using the coefficient 8744; because, 13146, bears the precise same proportion to 8744, that 3 inches bears to 2. And, with very accurate values to all the symbols, I think you will find that my coefficient 12000 in the formula $I = \frac{V^2}{12000 R}$ or $I = \frac{V^2}{2R} \div 6000$, where $R = \frac{a}{p}$, would give you very nearly the precise truth; at least 45 per cent. nearer the truth than the coefficient and formula used in constructing that important aqueduct.

The velocity at the dam, "in case the dam were removed," I left for you to ascertain. It is or should have been, one of the elements in projecting your "dotted black line;" for until you know how high the water would have stood at that point, you have no base for the dotted black line; you have nothing to start it on. This is the most important point in this controversy, and I hope you will be enabled to examine it. All the subjects in this letter preceding this paragraph, are merely collateral to the point at issue, and may well be omitted. Because, if you find that 800 cubic feet of water per second, passing that point without a dam in a natural channel only 75 feet wide, will stand as high or higher than it did at the same point when passing over a perpendicular dam and raceway extended by widening the river to 132 feet, then you will have no occasion for the dotted black line, or for the formula that projected it.

You do not appear to understand the reasoning in regard to n feet near, and n feet distant from dam. Your fig. No. 2, presents a natural dam intervening between wheel and artificial dam, and is a beautiful illustration of the subject, thus



B, a base line and bottom of wheel. D, the dam. N, a natural dam. W, the wheel. *a*, the surface at low stage of water in natural channel. *b*, the surface in same stage of water over dam. *c*, the surface over dam with an additional flood of 20 inches depth added to that before in the river. *d*, the surface in natural channel with the additional flood of 20 inches depth added to that before in the river. n, shall represent the feet between D and N. *n*, shall represent the feet between N and W. n and *n* shall be equal, n′ shall be the sum of inclination due to n. *n′* shall be the sum of inclination due to *n*. D′, N′ and W′ shall be stations *n* feet apart for dip of inclination. For a low stage of water in the natural channel, the dip or sum of inclination at station D′ shall = − 30, at N′ = − 3, at W′ = *o*, all counting from the base line B, and the surface line is at *a*. Now is n′ > *n′* and D does not influence the surface at W, erect D, and the surface line will follow *b*; then the dip or sum of inclination at D′, shall = − 3; at N′ shall = − 2; and at W′ shall = −0. Now is n′ < *n′*, and the river shall be damed or weired to affect the surface or line *b*, touching B at W. Then add a flood of 20 inches depth to that already in the river, and 20 + 0 = + 20 at W′; 20 + − 2 = + 18 at N′; and 20 + − 3 would equal + 17 at D′; but D is a perpendicular dam, and if as wide as N, it must by the law of falling bodies, discharge the same quantity of water in the same time with *less* height of column, or less R than is due to N, which has an angle *less* than 90 degrees, and this would serve all our purpose in this argument; but in the case we are discussing, the dam D is extended into a basin that is wider than N, and wider than the river, and hence D can discharge the same quantity with a column about one-half that due to N, and therefore, 10 + − 3 = + 7, or in other words, the surface line *c*, will be plus 7 at D′, plus 18 at N′, and plus 20 at W′, showing that n′ and *n′* are reversed, and as n′ > *n′*, showing that D has ceased to affect *c* at W′, because, N rose superior to D, or, N maintained its natural height, while D, from the law of falling bodies, discharged the same quantity with *less* R, or *less* height of column. May I hear from you at your leisure.

Yours, &c.,

C. F. DURANT.

WEST NEWTON, Aug. 8th, 1849.

DEAR SIR:

As we differ so amazingly with regard, both to correctness of facts and soundness of arguments, I utterly despair of our ever coming to an agreement, by letter at least; and feel that it would not be of any use to continue our correspondence, which, hitherto, has abounded so much in simple assertions and contradictions. Could we meet together somewhere and talk these matters over, perhaps we might soon come to an agreement, and I should like it very much could we do so, but fear our respective engagements would prevent such an arrangement.

My brother has promised to make some new measurements for me, and when these are received, I intend to make a thorough revision of my calculations,—correcting the error in the quantity of water per second, which, instead of being 800 feet, as obtained by *my* formula, (no one else *deserves* the credit of that) was considerably less. I intend also, to make whatever correction ought to be made for original width of stream at the dam.

It would have gratified me very much, if you had been pleased to state, how you would accommodate your formula to the known state of things on the Housatonic. You object to varying perimeter from the simple width and twice the depth of stream, and you also object to changing the coefficient $\frac{1}{12,000}$ to suit the circumstances of each case. Something must yield, otherwise $\frac{V^2}{12,000\ R}$ will not equal I in one case out of twenty on the Housatonic. I should infer, from what you say about a certain *line* of water-way, that you would change the depth so as to allow for the effect of a rough, rocky bottom. If this be so, will you inform me by what rule you would fix the depth? I should be very glad to receive this information from you.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

JERSEY CITY, August 10th, 1849.

E. S. CHESBROUGH—

DEAR SIR:

In your letter of 8th instant just received, you despair of coming to an agreement by letter, and suggest that a meeting might soon bring us to an agreement.

I will be happy to have you call on me at any time, and will cheerfully discuss the matter with you, but I think a continuation of our written communications will avail much more than any conversations; because, if we fail in coming to an agreement, then, the entire correspondence being recorded, we may submit the whole matter to others more learned than ourselves, to examine and decide on the questions at issue. In this enlightened age and in this highly favored country, there are many men whose skill in science generally, and in mathematics particularly, will enable them on a perusal of this correspondence and the documentary surveys, to come to a correct conclusion and decision on the points at issue.

I do not, however, despair of yet having a perfect agreement with you on all the important points in this controversy. If you will carefully examine and correctly answer the two concluding paragraphs of my last letter, there will then, I think, be little or nothing left to disagree about. One of those paragraphs relates to the height at which the water would have stood on the 23d April, the time of your survey, at Day's dam; in case the river had remained in its natural state with a channel 75 feet wide, instead of the dam and raceway extended to 132 feet by an artificial widening of the river. This is the base or foundation of all our disagreement; all the other matters that we have discussed were merely collateral.

In your survey and report you state, that Day's dam causes a rise of 7½ inches at the B. W. Co.'s wheel, as shown by a dotted black line, commencing at the dam, (projected by a formula that you have given) and intended to represent the surface of water in case the dam was removed. You invited me to point out the errors in that report; on that invitation, I pointed out one very important error,—the base of all your estimates for raising the water 7½ inches on B. W. Co.'s wheel. I pointed out the total absence of any base to start the dotted black line on; I showed its position, or start at dam, to be a physical untruth,—a physical impossibility. Up to the present time, you have

not corrected that *fatal error*. The penultimate paragraph in your letter of June 21, 1849, does indeed notice the subject, but in language that is not found in any mathematical vocabulary.

The illustration that I gave you in my last letter, in regard to *n* feet near and *n* feet distant from dam, is worthy of your attention and of some answer from you. Your survey for April 23, 1849, shows that the sum of inclination for *n* feet near dam, was greater than for *n* feet distant from dam. The relative height of dam and wheel, beside the information you have in the printed report, shows that n′ near the dam is less than *n′* distant from dam, in a lower stage of water, when the river is dammed without affecting first wheel above.

In answer to your special inquiry, I explained the cause of the relative values of inclination near and distant from dam in my letter of May 21st, and showed that it afforded physical proof that Day's dam could *not, by any possibility*, ever raise the water at B. W. Co.'s wheel in any flood, however great. The last paragraph in my letter of July 30th is entirely devoted to a further illustration of that subject, and yet, from first to last, you have not answered on that important point; a point of paramount importance in this controversy, because, it will settle the whole sum of disagreement: it will show that Day's dam, not affecting the first wheel above in a low state of the water, could never affect it in any freshet, however high the water may rise.

You very strangely omit to discuss the important points, while you are very profuse on matters that are merely collateral, or that have no bearing on the subject at issue. In your letter of 8th inst. you say, that you "intend correcting the error in the quantity of water per second;" while in your letter of July 2d, you say, "a diminution or increase of the quantity passing per second, has no effect in changing the computed height at the different stations of the dotted black line." If your formula is not affected by quantity, why change the quantity? If quantity is an important item, then why not abandon your formula? Why do you remain silent on the elements and on the fundamental principles of the subject under discussion? Why so profuse in assertions that have no foundation in truth, and which you do not even attempt to support by any mathematical law? It is *not* true, as stated in your report, "that the ordinary rules laid down in hydraulic works for estimating the inclination of streams of uniform width and depth, could not be applied to the [Housatonic,] even for the shortest spaces." Du Buat's laws are universal; they are the laws of running and falling

water, wherever found in the universe. The Housatonic cannot be excepted; it is a river of running water, and is subject to all the *physical* laws that govern running and falling water. HE, who notes the sparrow's fall; HE, who hears the raven's cry; HE, who tempers the wind to the shorn lamb, does not change HIS *laws* to suit the matter of HIS creation; but, HIS matter, elementary and organic, is tempered to HIS *laws*.

$\frac{V^2}{12000\ R}$, where $R=\frac{a}{p}$, is the law by which water runs on all rivers and on all aqueducts. The Housatonic and the Cochituate are both subject to that law; and, whenever $\frac{V^2}{12000\ R}$, does not$=$ I, it is because you have distorted, or given false values to one or more of the symbols, a, p, V, R. The area of a vertical section is represented by a; the area must be the correct measure of the section; it must be the correct measure of the section in which the water flows. The perimeter p, is the line that bounds the bottom and sides, neither more or less. When rocks occupy a part of the channel, the space occupied by the rocks, is clearly no part of the area or water-way; because, it is HIS universal law, that *two matters cannot occupy the same space in the same time.* And hence, when any matter obstructs the flow at bottom or sides, the surface must rise to meet the imperative requirements of the law $I=\frac{V^2}{12000\ R}$.

You ask, "how to accommodate the formula to the known state of things on the Housatonic," as if the law of matter must bend to accommodate the requirements of man. $\frac{V^2}{12000\ R}$, will always equal the inclination for such distances on the Housatonic as embody the the precise values in the formula. On all rivers that are as variable as the Housatonic, the values in formula, change frequently in distance of 5 or 10 feet. To have true and correct results from the formula for any particular distance, you must give true and correct values to the symbols for that particular distance; and, from the very variable width and depth, those values will frequently be required for unity, or for distances of one foot.

I shall be pleased to hear from you.

Yours, &c.

C. F. DURANT.

WEST NEWTON, Aug. 14th, 1849.

DEAR SIR:

Yours of the 10th inst. was received this morning. Its contents merely confirm me in my previously formed opinion, that it is not likely that any benefit can result either to Mr. Day or to ourselves, by a continuance of our discussion. If I was once green enough to suppose that you would yield in the least to any arguments or opinions of mine, when opposed to anything you have asserted, I have completely changed my mind since. Your letters abound in expressions, which if true, prove most conclusively that I am an ignoramus, attempting what I do not understand; and that your *mere* assertion is sufficient proof of the fallacy of my arguments and conclusions.

Without attempting to answer your statements in detail, I will simply say, with regard to one point, that of correcting the "*fatal error*" as you are pleased to call my omitting, through ignorance of its existence, to allow for the original contraction of the Housatonic, at Day's dam. I have promised you and Mr. Day both, to revise my calculations in this respect, after receiving my brother's measurements. If you are not satisfied with my promise to do so, I have nothing better to offer. My brother's report was not received till this morning, and it may be ten days or more, before my duties here will allow me to make the revision. You may depend upon one thing however, that this revision, which is to be made in strict accordance with the rules and principles laid down by Du Buat, will differ very materially from your statements and assertions.

My reason for not replying to your arguments about *n* feet at the dam having a greater inclination than *n* feet at the wheel, proving that the dam had therefore no effect upon the wheel; is, because I have already shown (to my own satisfaction at least) that deductions drawn from such premises, are not at all conclusive; and because your last arguments are based upon unnatural suppositions, which are afterwards brought forward as proofs. To explain myself, you make a diagram, (an exact copy of which is enclosed) and then suppose that after the erection of D, with a low stage of the river, the inclination between D and N will be less than that between N and W. Now the diagram shows, that in the former case the water is not so deep as in the latter; consequently the inclination at its surface must be *greater*, to pass the same quantity of water. But without this unnatural supposition, as well as another, that a freshet of 20

inches at W, would necessarily rise 20 inches at N,—mere suppositions are not proofs, be they ever so natural. If you will take any case, similar to the one represented by your diagram, assume your dimensions with regard to width and depth of stream, and then calculate what would be the surface, inclinations, and altered depths for a given quantity of water; you will, if Du Buat's rules are followed, have proof that amounts to something.

There is no probability at present that I shall visit New York very soon.

It would gratify me very much to have this whole matter from beginning to end (after my promised revision shall have been made,) laid before some competent third person; especially if that person should be an eminent professor of Mathematics, or of Natural Philosophy, in any of the New York Colleges.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

P. S. Your assertion that $I = \frac{V^2}{12000\ R}$, is the universal law of uniform motion of water is not sustained by Du Buat. In the first place his *universal* formula is altogether a different affair, (See Vol. I. p. 61.) Neither are you sustained by him, in your assertion, that *perimeter* is never to be more than W + 2 D, either by his definition, faithfully interpreted, (Vol. I, p. 21—art. 17) and most evidently not by his illustration, Vol. I, page 298.

JERSEY CITY, August 16th, 1849.

E. S. CHESBROUGH—

DEAR SIR:

Your letter of 14th inst., is at hand. $\frac{V^2}{12000\ R}$, where $R' = \frac{a}{p}$, is the inclination of running water, and it is the *law* that governs running water on all aqueducts and all rivers in the universe, as shown by Du Buat, from page 1 to *Fin.* I was not discussing a "formula;" Du Buat employs very elaborate formulas, and those formulas are always adapted to the points he is discussing. I did *not* state that "perimeter is never to be more than W + 2 D." I said, perimeter

is the bottom and sides of a river, neither more or less: the sides may not be vertical, but inclined, and it is then greater than W + 2 D: the bed and sides may be a half circle, and it is then greater than W + 2 R, as shown in the first paragraph of my letter of July 20th, 1849. The experience on the flow of water on the Cochituate aqueduct, confirms the law $I = \frac{V^2}{12000\ R}$, and the Housatonic will show the same result for any distance, where the correct values are given to the symbols.

There is surely nothing "unnatural," in supposing the bed of a river at its mouth, to be *lower* than at the source or fountain; all rivers of running water are *supposed* to be so; now, if a dam is erected at the mouth, high enough to affect the water at the fountain or source, then clearly, the water must be deepest at the mouth, so long as the river remains dammed, or the surface remains affected at the source. The diagram in my letter of July 30th, is made on that principle; a a principle that is surely applicable to the Housatonic, and to all rivers of running water on this globe. The natural dam N, may very naturally be supposed of the same width as W, and then, when the river is dammed below and over N, an additional flood must raise the surface equal at W and N, because, at both those stations, radius is equally augmented. If the river was *not* dammed below N, and the widths remain equal, then an additional flood could not raise the surface as much at N as at W, because, n′ would then require less additional radius than *n*′, where $I = \frac{V^2}{12000\ R}$, and $R = \frac{a}{p}$. In all additional floods, the surface must rise less at D; because, D is wider than N, and also because the water at D, descends over a perpendicular dam, and, by the law of falling bodies, requires less additional radius to pass the same quantity in the same time than is due to any inclination of less angle than a perpendicular.

In pointing out the principal error in your report, that of assuming the original river to have been of the width and depth of the dam and raceway as you found it on the 23rd of April, I did not impute or intend to impute, any lack of scientific knowledge on your part; you may well have supposed that the raceway and the width of river at dam, were natural, and had always been as you found them in width and depth. I knew they were not natural, but artificial, and acting under your express invitation, I deemed it right to inform you of the fact. Your calculations, assumed that the river and raceway,

were to remain as you found them, in case the dam was removed: the facts, although unknown to you, were very different; in nature, there was no raceway, and the river itself, was naturally much narrower; such facts, were fatal to all your assumed widths and depths, and were fatal to all the estimated heights for your dotted black line, because, a narrower channel requires greater radius to pass the same quantity in the same time, and it left your dotted black line entirely without a base to start on. In pointing out that fatal error, I surely imputed no lack of science or of intellect to you; you could not make use of facts that were not within your knowledge. I have just cause to complain of you for not correcting the error when I first pointed out its existence; however, as you have promised now to correct it, I am satisfied that we shall soon come to an agreement. May I hear from you at your leisure?

Yours, &c.,

C. F. DURANT.

BOSTON, Aug. 20, 1849.

DEAR SIR :

Yours of the 16th was received this morning. I would willingly continue the discussion we have been so long engaged in, if I thought it would do any good to any body, at all equivalent to the time it consumes, and if we had a common basis to rest our arguments upon. But, as it is very clear to my mind, that neither is the case, I must beg you to excuse me.

I hoped to be able to send the revised calculations on the last of this week, but, in consequence of my brother's having made an important omission in his work, I do not expect to be able to do so before next week. Please mention this to Mr. Day, if you should see him.

Yours respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

NEW YORK, August 21st, 1849.

E. S. CHESBROUGH—

DEAR SIR:

Your letter of 20th instant is this moment received. The basis to rest our arguments upon, is the physical laws that govern running water applied to Day's dam, and mill privilege on the Housatonic. The basis is surely common to both of us, and this correspondence will show how closely I have followed the text.

I regret that you deem the good to flow from this discussion, is not equivalent to the time it consumes. Physical laws, the subject of our discussion, are ETERNAL TRUTHS. They are, at all times, worthy of the highest consideration from the most intellectual men; and, when these laws are applied to the daily business of man, they become of paramount importance to the professional engineer; whose profession is, to lead the handicraft in building conformably to the great truths of nature. My own time, in this discussion, has been very pleasantly spent, and I feel, that the attention devoted to the subject, is not without profit—to myself at least.

Mr. Day is out of town at present, and is expected to return in two or three days, when I will deliver your message to him; in the mean time, I wait with much pleasure, to see your revised calculations.

Yours, &c.

C. F. DURANT.

WEST NEWTON, Sept. 5th, 1849.

DEAR SIR:

I intended writing you a few lines day before yesterday, in relation to my revised estimates, but was unexpectedly prevented by the sickness of a sister.

Mr. Day has, doubtlessly, received my communication before this. I know, from the discussion we have already had, that you will not agree with me; and feeling satisfied that, in the main, I am right, I can see but little advantage to be derived from recommencing the discussion.

I wish to explain one thing however, that you will probably notice on examining my communication to Mr. Day. My brother's levels of the 6th of June last, were misunderstood by me at first; that is, I

supposed he used a different nail from the one he actually used. This, then, makes the fall at the dam 26 inches, for such a stage of the river as existed on the 6th of June. Hence, on the 23d of April, when the water was lower, the fall at dam must have been over 26 inches, instead of only 23, as I have heretofore told you.

Yours, respectfully,

E. S. CHESBROUGH.

C. F. DURANT, Esq.

JERSEY CITY, Sept. 7th, 1849.

E. S. CHESBROUGH—

DEAR SIR:

I have carefully perused your revised calculations, or as you express it in the first paragraph, "a much more thorough investigation of the subject of flowage caused by Day's dam." Your highly commendable and persevering efforts to arrive at the truth in this question, induces me to point out a few more important errors in your report and in your revised calculations, that will need a yet more thorough revision or rëinvestigation, before your accommodating formulas can make an approximation "that expresses more faithfully the facts of nature."

You now make the quantity of water per second, "not over 600 cubic feet for 23d April, instead of 800;" and you say you was led into that error by "using a wrong rule, of respectable but not sufficient authority." It is an error that might affect the cause of science, to assume that any "respectable authority" would recommend your formula $\frac{Q}{L} = H\left(a\sqrt{2gH} + V'\right)$ as given in your letter of June 2d. The only respectable authority for the use of that formula, is your own words in your letter of June 2d, where you say "it is easy to get at a correct result in a short time, a result, too, which I find *agrees remarkably well with observations*." The very great change from 800 to 600 feet per second, shows that either your formula or your "observations," must have been very remarkable; but two remarkable errors, cannot make one physical truth, however respectable the authority that committed the errors. If the rule that gives you "not over 600 cubic feet per second," agrees equally well with observations, it must be equally remarkable; for by all respectable

authority known to the world, both 800 and 600 are wide of the truth: one errs by giving too much, while the other errs by giving too little. By your own showing the column was $16\frac{1}{2}$ inches on dam while one wheel, as shown by your recorded observations, was discharging as much more as would add $1\frac{1}{2}$ inches to column, making a height or column equal to 18 inches high by 112 feet long. Dr. Robison's formula in reducing Du Buat's elaborate theorems to English measure, give $Q = \frac{l\sqrt{130.032H^3}}{144}$; and with the values, the quantity in cubic feet per second, is $= \left(\frac{112\ \sqrt{130.032 \times 18^3}}{144}\right) =$ in round numbers 680, about the same as shown by the tables. Respectable authority thus shows, that both your original report, and also your revised calculations, are about equally erroneous; and if either, or both of those errors, "agree remarkably well with observations," it must indeed be a *very* remarkable practice.

You have also, a very remarkable way of applying Du Buat's rules for showing the rise occasioned by piers of bridges, to ascertain whether the water would have fallen if Day's dam were removed: and then your brother's very convenient soundings are graciously assumed at 2 feet deep, making velocity 2.308 for a river of 130 feet: now, this is all assumption; the *river* at dam was never 130 feet. The dam and raceway, are together, equivalent to a *dam* of 130 feet for the discharge of water, and the velocity over a perpendicular dam, as I showed you in my letter of July 20th, would have been 5 feet per second for April 23d. But in your remarkable practice, elements are of no importance; for in the 7th paragraph, after your accommodating formula has given .009 inclination, you "prefer to use .110 instead," because, "observations on the Housatonic has shown the formula used, gives not more than one-twelfth the actual amount." In my letter of July 30th, I showed that your formula gave only about $\frac{1}{12}$ part of the truth, because, you had distorted the values in that proportion; and it may be well now to assume distorted values, and then multiply the distortions by 12, as in "$.009 \times 12 = .110$," because, although two wrongs cannot make one right, a multiplicity of errors may correct themselves in some remarkable way; and, the admiring world would then observe the beautiful adaptation of Du Buat's rules for ascertaining the rise occasioned by piers of bridges, to show what a large amount of truth will rise from a multiplicity of errors.

By your letter of the 5th inst., this moment received, I find that some remarkable "nail" "makes the fall at the dam 26 inches for such a stage of the river as existed on the 6th of June, hence on the 23d of April, when the water was lower, the fall at the dam must have been over 26 inches." That is very correct, no doubt; it is, I believe, the same measurement you gave as 23 inches in your letter of June 26th, while in your report, you assume it at 24 inches, and is referred to in your letter of June 12th, when you say "my brother's measurements sustain me in what I have said in regard to the dam." A very remarkable way indeed, and sustains you remarkably well; because, as "*observations on the Housatonic has shown the formula used, gives not more than one-twelfth*" *part of the truth*, and as you are "*unable to find anywhere a rule for rough channels, that expresses more faithfully the facts of nature, when the same portion of the channel and the same quantity of water per second, and only different depths and velocities are taken into account*," it is well to start low enough, even to twelve times the true depth, so as to make it a suitable base for such an accommodating rule or formula and elements, that gives only one-twelfth part of the truth, when used on that unnatural Housatonic; a river so rough, so distorted, so repulsive to the science of Hydraulics and to all physical laws, may well bear the most fictitious and distorted measurements and formulas.

In all your letters, your report, your recorded elements and revised calculations, you do not show that you ever knew the amount of fall at Day's dam on 23d April. You assumed it at 2 feet, a mere guess; when I pointed out the error in my letter of June 2d, you then sent your brother to measure it. The fall when your brother measured it, or your recent measurements for your revised calculations of 3d inst., do not show what the fall was on 23d April; because, as shown in my letter of June 28th, the width of dam and width of river below dam, will, at every change of flood, change the relative heights above and below at dam; and you have not yet shown even an attempt to compute the relative heights on 23d April, from any elements obtained on any subsequent day, when the flood above stood at any different or particular height. If you should now attempt to compute the relative heights for 23d April, it will be necessary for you to know that since your report of May last, Mr. Day, by my advice, has raised his dam an average of full five inches higher than it was at the time of your survey, and the removal of obstructions from

750 feet below dam, has lowered the water in his raceway full 12 inches, the whole giving him a water-fall of 17 inches more than he had on the 23d of April last.

Mr. C. B. Culver, the gentleman who has charge of Mr. Day's factory at Great Barrington, wrote on the 21st ult., that in the then very low stage of water, with a full sheet running over Day's dam, the Berkshire Woolen Company's tail race *was perfectly dry* for 72 feet below the wheel, on the closing of their gates. A copy of Mr. Culver's letter was sent to you from Mr. Day's office on the day it was received here. Now, as Mr. Day has added five inches to the height of his dam since your report, and as shown by Mr. Culver's statement, without affecting the first wheel above in a low stage of the river, it shows that you committed one very great and very serious error, when you stated in your report, that your "observations shows very conclusively that any addition to the height of his dam, would raise the surface of the water at the B. W. Co's wheel." The dam has been raised five inches while the surface has not been raised at the B. W. Co's wheel in a low stage of water, and as shown in my letter of July 30th, (unanswered thus far by any argument from you) it is a physical impossibility for the dam, ever to increase the rise at B. W. Co's wheel, however great the flood may be.

I must now call your attention to an important error in your levels; an error, that is fatal to your report, fatal to your revised calculations, and fatal to all your estimated perimeters and inclinations. Your "full black line, showing the surface of the river on 23d April," has an erroneous inclination. From station 0 to station 11, or from dam to near B. W. Co.'s wheel, you have given it an inclination of 11¾ inches, which is 5 inches more than the truth, and more than destroys all the back-water that your elements and your formula have piled against the B. W. Co.'s wheel. Your report gives the following heights, all in inches above base line,—

			Station 0.	Station 5.5.	Station 11.
Lower red line,	showing surface,	April 29th,	12¼	16¾	20
Full black line,	ditto	April 23d,	11¼	15½	23
Lower blue line,	ditto	May 21st,	10¼	13¾	16
Dotted blue line,	ditto	April 19th,	9¾	12¾	15

The full black line, you will perceive, starts one inch *lower* than lower red line, and then *crosses* it and rises 3 inches *above* it at station 11. That is a *physical impossibility:* two or more surface lines,

starting on same dam and same river at different heights of flood, *cannot* cross each other by *any* physical law; hence, either the full black line, or all the other lines, must be erroneous and false; because the full black line starts only $1\frac{1}{2}$ inches above the lowest, or dotted blue line, and arrives at station 11, 3 inches higher than the highest, or red line; and would therefore, *cross every* line, which is a physical impossibility, when the flow of water is governed by inclination of surface $= \frac{V^2}{12000\ R}$. And hence, it follows, are either of your surface lines correct? and, if yea, which of them? That we will now examine.

My letter of July 30th shows, that for all increased floods when dam has ceased to affect the wheel above, then the sum of inclination for n feet next to dam, is greater than for n feet distant from dam. The following is a tabular statement of the inclination of your surface lines; the sum of inclination expressed in inches.

	Station 0. Sum of inclination or rise at dam.	Station 5.5. Sum of inclination or rise from 0 to 5.5.		Station 11. Sum of inclination or rise from 5.5 to 11.
Lower red line, for April 29th,	0	$4\frac{1}{2}$	$>$	$3\frac{1}{4}$
Full black line, do. April 23d,	0	$4\frac{1}{4}$	$<$	$7\frac{1}{2}$
Lower blue line, do. May 21st,	0	$3\frac{1}{2}$	$>$	$2\frac{1}{4}$
Dotted blue line, do. April 19th,	0	3	$>$	$2\frac{1}{4}$

Thus your full black line for April 23rd, falls under the anathema of the law. It is physically impossible; it is physically false; because, the inclination for n next to dam, is *less* than for n feet distant from dam. The lower red, the lower blue, and the dotted blue line, show a reversed sum of inclination for n feet near and distant from dam, and are, therefore, approximations to the truth. The dotted blue line was taken by your brother and yourself when I was present. Yourself and brother labored assiduously at that operation, and, I have no doubt, the manipulation was correctly performed: it comes within the law $I = \frac{V^2}{12000\ R}$; it shows I for n feet near dam, is greater than I for n feet distant from dam. The first 550 feet from dam rises 3 inches; and the next 550 feet, up to 1100 feet from dam, rises $2\frac{1}{4}$ inches, making in all a total of $5\frac{1}{4}$ inches. This same dotted blue line, as shown in the postcript to your letter of May 8th, gave 0.19 feet, or 2.28 inches for first 325 feet from dam; and, in my letters of May 11th and May 21st, I showed that it gave the most positive physical proof

that Day's dam could *not* affect the surface at first wheel above; and also, that for all increased floods, Day's dam could be raised higher without affecting the first wheel above. When in the railroad car, departing from Great Barrington, you said to Mr. Day, Mr. Emerson, and myself, that the "levels for 19th April, [dotted blue line] showing a declivity of 2.28 inches near the foot bridge, and 5.24 inches in all to near the Company's wheel, you *knew* to be correct; because you had made an entire circuit and brought the levels down to starting point, where they balanced within $\frac{1}{16}$ of an inch, and having measured twice from the dam to footbridge, you was *positively certain* the levels were correct." The italicised words are those which you gave in the most emphatic manner.

Now, I also "*know*," that the dotted blue line for April 19th, is very nearly correct; and it proves most conclusively, that the "full black line for April 23d" is erroneous and false. I hoped to save you from the mortification which this exposure must occasion, by pointing out a mode of avoiding this unpleasant refutation; but you preferred another course, and you must bear the evil that follows a violation of physical laws.

The error in the full black line, you must perceive, is *fatal* to all your estimated inclinations and perimeters, both in your report and in your revised calculations: and you cannot now remedy the evil by changing its inclination, or by hanging the line on a different nail. For if you attempt to raise the end next to dam, then you raise a column that will flood you with 950 cubic feet of water per second; or, if you attempt to depress the end next to B. W. and Co.'s wheel at station 11, then your "dotted black line" and the long table of estimated inclinations and profuse perimeters, will be caught on the "*wrong nail*," and be left suspended in the cold air, several inches above the surface elevation on the 23d of April, 1849.

Yours, &c.

C. F. DURANT.

APPENDIX.

Referred to in the letters as "PRINTED REPORT."

TO WHOM IT MAY CONCERN.

Having been notified by the "Berkshire Woolen Company," by note, to remove the dam from the Housatonic river, which I have recently erected upon my own property, under the direction of an able engineer and mill-wright—of which the following is a copy :—

"To Horace H. Day and all others interested in the dam across the Housatonic river in Gt. Barrington nearly opposite Samuel Rossiter's dwelling house, and built or maintained by you. You are hereby notified that the building of said dam and all obstructions to the water, placed by you in the river, are injurious to, and a nuisance to our water-privileges and rights in the river above and to our works on the same stream above said dam ; and we object to said dam's remaining, it sets back the water to our injury and otherwise injures us, and interferes with our legal rights and possessions ; and we give you this repeated notice forthwith, to remove said dam and all obstructions placed or maintained by you in the river below our mills, works, and dam.

A. C. RUSSELL, Agent
Gt. Barrington, Nov. 13th, 1847. For the Berkshire Woolen Co.

I have caused a new Survey to be taken by one of the most scientific men in our country, who fully sustains the calculations made by Mr. Searfoss, as will appear from his Report following :—

H. H. DAY, Esq., JERSEY CITY, 20th Nov., 1847.

SIR,

On Wednesday the 17th of November inst. I made a survey of the dam and works of the Berkshire Woolen Company, above, and the dam and works in progress of construction by you, below, on the Housatonic river, at the town of Great Barrington, in Berkshire county, Mass. The survey was undertaken with special reference to the amount of fall, and also to ascertain the height to which you may dam the river without interfering with, or injuring in any way, the Berkshire Woolen Company's water power.

On my arrival at Great Barrington, I learned from a large number of gentlemen, that the idea of water "piling up" or backing up stream," was entertained by nearly the entire population, including gentlemen of large practical as well as theoretical acquirements. They stated that a dam would so retard the current, as to produce "a piling" or accumulation of water above the level, against the wheel in the apron above. Opinions generally, fixed the amount of water thus "backed up" or "piled above the level" of your dam, against the Berkshire Woolen Company's wheel, at from fifteen to eighteen inches, which, in twelve hundred feet—the distance between your dam and the Company's wheel—would equal from one and a quarter to one and a half inches per hundred feet. The high respectability of the gentlemen who maintained the "piling" of water, induced me to embrace in the survey, such measurements as I deemed applicable to a practical demonstration of the truth, independent of the known physical laws that govern the science of hydraulics.

I have devoted that attention which the important results depending on this survey seemed to require, and have duly considered my own responsibility in advising you of the exact height to which you may dam the river, without injury to the privilege above. Less than the true height, would cause you a loss of so much valuable power, while more than the true height—even the fractional part of an inch—would cause a corresponding flow or back-water on the Berkshire Woolen Company's wheel, and render you liable in a suit at law for the diminished power and other damage thereby sustained.

Having already given you the amount of fall and weight of water at your dam, with other particulars required in the construction of your works, I will not here repeat the details then furnished, but will confine my remarks to the effect which your dam may have in flowing the apron, or raising back-water on the Berkshire Woolen Company's wheel.

At 12 o'clock noon, on the 17th inst., there was six and three-eighths inches back-water on the Company's lowest wheel, and, at the same time, the surface of the water at your dam was two and eighty-one-hundredths inches lower than the surface at the Berkshire Woolen Company's wheel. The distance between the two places is about twelve hundred feet. There was ten inches of water on your dam of one hundred and twenty feet in length, there is besides, a sluce or gateway twenty feet long, that is now closed while the works are constructing. Making the surface of water on your dam a base line, and equal 0 or zero, I found the surface, at a point distant three hundred and twenty-five feet from your dam, to be nineteen-hundredths of an inch, plus; at a point six hundred and fifty feet from your dam, the surface was sixty-nine-hundredths of an inch, plus; and in the apron at the Company's wheel, distant about twelve hundred feet from your dam, the surface was two and eighty-one-hundredths inches, plus.

If the cause of difference of level proceeded from retarding the current at your dam, then, by the physical laws which govern motion in all matter, the effect should be at least equal at the point where the retarding or opposing force was applied; while the survey shows the difference of level to be three times greatest on the section most distant from your dam, and clearly demonstrates that the backwater on the Company's wheel is not caused or influenced in any degree by retarding the current at your dam.

The backwater on the Company's wheel is caused by placing it too low; it extends to within one inch of the bed of the river, and, whenever there is an average depth of seven and three-eighths inches of water in that part of the river, the backwater on the wheel must equal six and three-eighths inches, simply because it is placed that depth below the natural level.

The current of water is due to the height of its column; like all matter on the earth's surface, it will fall perpendicular about sixteen feet, less the resistance of the atmosphere, in the first second of time. Its descent on a river or inclined plane, is due to the same cause, its inherent gravity, and it will move to a level on any area or plane in the ratio which the inclined angle of the plane may bear to a perpendicular. Hence, you may raise the water on your dam two and eighty-one-hundredths inches, before you can, in the least degree, affect the height or flow of water at the Company's wheel.

The motion of the water over your dam being due to the height of the column, while the quantity discharged is proportional to the length of the dam; hence, it follows, that an open sluice or gateway of twenty feet, added to the dam of one hundred and twenty feet, will lower the column one-seventh part; the column of ten inches will give as one-seventh part, one and forty-three-hundredths inches in addition to the two and eighty-one-hundredths difference of level. And hence, at all times, when your gateway is open, you may add four and twenty-four-hundredths inches to the present height of your dam without the least injury, and without causing a flow on the Berkshire Woolen Company's wheel of the one-hundreth part of an inch. The result will be the same in all stages of drought or freshet, it cannot be affected whether the water in the river is high or low.

C. F. DURANT.

Now, having become entirely satisfied that my dam does not, in the *least degree* affect the water right of the "Berkshire Woolen Company," and desiring that no act of mine shall be construed or believed to be an intentional trespass, and with all due deference to the opinions of others, I propose to make a practical demonstration of the truth of Mr. Durant's statement and calculations, in a maner, which will at

once prove the sincerity of my own convictions, while it will afford an opportunity to those who differ from me in opinion, to profit by the operation, if they are right; at the same time, barely saving me from loss, if they are wrong.

I offer the following proposition, viz.:—Two disinterested persons shall be chosen by the Berkshire Woolen Company, and two by myself—the four to choose a fifth. These five shall be the judges. I will then deposite in the Mahaiwe Bank, to their credit, two thousand dollars, on condition that the Company, or any of its friends, shall deposite the like sum, in like manner. I will then remove my dam from the river, and if by reason of such removal and the absence of the dam, the water shall be found lowered on any of the Berkshire Company's wheels, to the amount of one inch, the judges shall immediately pay over to the Company the four thousand dollars; But if, on the contrary, the water is found not to have lowered, in consequence of the removal of my dam, to the extent of one inch, then the four thousand dollars shall be paid to me:—The judges to settle all questions of detail, and the decision of a majority to be binding on both parties. HORACE H. DAY.

New York, Nov. 23d, 1847.

Referred to in the letters as "Letter to Mr. Emerson."

Jersey City, Sept. 3d, 1848.

Chas. N. Emerson—

Dear Sir,

Your letter, of 25th ult., requesting a statement of the Day matter, is at hand; it has probably been in the Jersey city office some days. Communications to my address, 21 Wall Street, New York, are delivered on the day of arrival.

"The piling of water," that is, causing a diminished quantity to flow in the same time by damming the river, is a physical impossibility: because, the flow of water on a river or plane, is due to its inherent gravity, and, the natural angle of descent or bed of the river, is not diminished or changed by a dam; and because, the dam by deepening the channel or water-way, will permit the same quantity of water to pass in the same time with less declivity in the upper sur-

face, while the descent of 90 degrees over a perpendicular dam, is in a ratio with its descent on a plane of less angle, less the friction in both cases; the dam causing the least possible amount of friction, being matter falling in space, less the atmospheric resistance.

The entire amount of declivity in surface, deduced from the natural current and area of water-way, required to pass the natural flow of water in the Housatonic river at Great Barrington, from the B. W. Co's works to Day's dam, is a fraction under two inches: the distance is about 1200 feet, or nearly one-fourth of a mile. Near the dam where the area is greatest, the declivity is least, and thence increasing by an infinite series, to the point near the Company's works, where the natural level was not changed or affected in any way by the dam. Thus the surface, or infinite series of columns, becomes a curve, whose difference of dead level at extreme points, requires a fraction less than two inches to pass the natural current in the time due to the natural bed of the river.

Before Day's dam was erected, the entire amount of declivity in surface between the two points, was three feet, as shown by Mr. Woodruff's survey.

On 17th Nov., 1847, I found by survey, that the entire amount of declivity in surface from Day's dam, to a point near the B. W. Co's wheel, was $2.\frac{81}{100}$ inches: showing nearly one inch more declivity than was required by estimate to pass the natural flow of water for the whole distance. The back-water on B. W. Co's wheel at that time, was $6\frac{3}{8}$ inches, and the wheel was within one inch of the bed of the river. There was at that time, a flow of full $7\frac{3}{8}$ inches water in that part of the river; showing, that the natural height of water in the river, and not the dam or any other obstruction, was the cause of the back water. The wheel to be entirely free from back water, must be sufficiently elevated to allow the natural flow or quantity of water, to pass between it and the bed of the river. I found by the same survey, that the top of dam was $12.\frac{81}{100}$ inches lower than surface of stream near B. W. Co's wheel, and at the same time, there was ten inches column of water on Day's dam.

On the 19th July, 1848, Day's dam being torn away, I made a reëxamination of the premises. By measurement on a bolt in a rock above the B. W. Co's dam, where the flow of water cannot be affected by any dam or obstruction below, I found the natural quantity of water in the river was $8\frac{1}{8}$ inches less depth, than on the 17th Nov. previous, to wit; on 17th Nov., 1847, the water was $9\frac{1}{2}$ inches above

bolt, and on the 19th July, 1848, the water was $1\frac{3}{8}$ inch above bolt; showing a diminished depth of water in the river, of $8\frac{1}{8}$ inches: at the same time, I found by measurement on a stone in the raceway below and near the B. W. Co's wheel, that the water had lowered $8\frac{1}{8}$ inches and no more, to wit; at said stone, in the raceway near the B. W. Co's wheel. I had taken my first back sight in Nov. 17th, 1847: the surface of water was then level with top of the stone on which the leveling stave rested, and on 19th July, 1848, the surface of water was precisely $8\frac{1}{8}$ inches below the top of said stone. These measurements, practically demonstrate that the water at said stone, below and near the B. W. Co's wheel, had never been raised in the least degree by the erection of Day's dam, and that it had not been lowered in the least degree by tearing away said dam.

From the B. W. Co's wheel, to the stone whence commenced the first back sight in taking the declivity of the river in Nov., 1847, there was a further declivity of about two inches, and deemed ample for the entire declivity of surface between the two dams; that declivity has since been destroyed, by excavating a portion of the rocky bed of the river at that point.

Day's dam does probably flow or raise the water some inches in the lower end of the B. W. Co's tail-race, but that does not in any way affect the flow at the Company's wheel, or diminish their power in the least degree: because, the principle of increased area in water way diminishing the declivity in surface, is applicable to that part as well as to all other parts of the river, comprised between the extreme points of curved surface, or infinite series of columns from Day's dam to the wheel of the Company, where the water power is available.

Yours, &c.,

C. F. DURANT.

Referred to in the letters as "MR. CHESBROUGH'S REPORT."

HORACE H. DAY, Esq., WEST NEWTON, May 23d, 1849.

SIR:

Having, at your request, during the week ending April 21st, surveyed your mill privilege in Great Barrington, Mass., with the view of ascertaining whether your dam causes back-water on the wheel of the Berkshire Woolen Company's Factory, or not, I would now submit the following report with the accompanying plan and profile.

The distance from your dam to the B. W. Co.'s wheel, as you will see by the plan, is about 1200 feet. The bottom of the wheel is $10\frac{1}{8}$ inches above the average top of your dam. The term *average* is used, because your dam is variable in height, as will be seen by referring to a longitudinal section of it on the profile. (The profile is drawn to a very distorted scale, for the purpose of showing very small variations in altitude, without requiring too much space for horizontal distances.) The inclination of the surface of the water in the river, between your dam and the B. W. Co.'s wheel, varies, of course, according to the quantity flowing in the stream. The profile shows what it was in several stages of the river while we were making the survey. In the highest stage, when the flash boards were off, the inclination was such as to submerge the wheel about 14 inches.

In order to ascertain whether this was caused by your dam, in part, or owing wholly to the freshet in the river, a series of observations, on two successive days, were made, on the effect produced by putting on and taking off flash boards at your dam. There was considerable difficulty in arriving at a satisfactory result in this way, on account of the variable quantity of water passing down the river. To detect any variations of this kind, the observations were taken at short intervals of time and during the greater part of each day, as will be seen by referring to the accompanying tables. To get, if possible, still more satisfactory results, Chas. N. Emerson, Esq. has since had a set of observations made in the night, when the mills above were stopped, and the state of the river remained very constant. A tabular statement of these, will also be found to accompany this report.

A careful inspection of these observations, taking the average of them, and leaving out extreme cases either way, shows very conclusively, that any addition to the height of your dam, would raise the surface of the water at the B. W. Co.'s wheel. The observations of April 19th show, that by raising the water (by means of flash boards) $1\frac{3}{4}$ inches at the dam, it was raised in the race just below the wheel about 1 inch. (At the same time, other observations on the same day, show that no rise took place at all at the wheel; but these form the exception, and not the general rule.) Those of the 20th show, that the removal of flash boards from the dam, causing a fall of the surface of the water there of 3 inches, was accompanied by a corresponding fall near the wheel of full 2 inches, and by one of $1\frac{3}{8}$ *in the river* opposite. (Not a single observation of this day can be adduced to show a

departure from this general result.) Those of May 21st, (Mr. Emerson's) show that a rise of 2¼ inches, caused at the dam by putting on flash boards, was accompanied by a rise at the wheel of 1½ inch, and in the river opposite of 1 inch.

At first, it occurred to me, that while these facts proved that your dam could not be raised any higher, without causing more back-water on the B. W. Co's wheel, it still might be just at that height, at which it first commenced to cause back-water on the wheel; in other words, that your millwright has been so skilful as to occupy the entire fall belonging to you, without encroaching in the least upon your neighbours.

In order to settle this question, my brother was directed to ascertain, with great accuracy, the height of the surface of the river, at intervals of not more than 100 feet, between your dam and that of the B. W. Co's. These levels started from my point of commencement, and did not differ one-sixteenth of an inch from mine, at the bolt in the rock above the B. W. Co's dam.

The result of these levels showed very conclusively, that the ordinary rules, laid down in hydraulic works, for estimating the inclination of streams of uniform width and depth, could not be applied here, even for the shortest spaces. This is owing to the bottom of the river being covered with large stones and rocks, and consequently being very rough. To ascertain the amount of resistance the water met with, beyond what it would have encountered in a comparatively smooth channel of uniform width and depth, so as to make use of this resistance in calculating the inclination of the river's surface in other cases, and bring out results agreeing with actual observations, has caused me a great amount of labor, and no little perplexity. At length however, my investigations, which have been made in every way that seemed to promise a satisfactory result, have led to the adoption of a comparatively simple rule. The application of this rule to four other stages of the river, to ascertain its inclination, showed an agreement with actual observation, in some cases almost exact, and in none varying over 8 per cent.

Applying this rule to ascertain what change would be effected in the river, if your dam were removed, the quantity passing being 800 cubic feet per second, it gave as the result a fall of 5 inches *on the river*, opposite the B. W. Co's wheel, and of 7½ inches about, in the race, just below the wheel. This last result is less satisfactory than

the former, and I would not be understood as asserting confidently, that either is within 8 per cent. of the truth; but the exact truth could not be ascertained without previous measurements, which it would be impracticable to make. Of this much however, I feel quite sure, that the results here given, are in principle correct, but in quantity or proportion may not be perfectly accurate.

Admitting the foregoing conclusion to be confirmed by other testimony as well as my own, it may be asked, what ought you to do to prevent back-water upon the B. W. Co.'s wheel; and, in case back-water cannot be prevented, what amount of damage does your dam cause to the B. W. Co.?

To answer the first of these questions with precision, would require a series of observations continued throughout a whole year at least; and the second, a more intimate and practical knowledge of mills than I possess.

With regard to the first question, it is very evident, that in extreme low water, your dam does not cause any obstruction to the B. W. Co.'s wheel. At what stage of the river the dam begins to cause back-water, is more than I could tell, even approximately, without more investigations than my present engagements would allow me to make. But were this point accurately determined, it could not be of much practical utility, unless the length of time the river stands at it were also known.

With regard to the second question, it seems to me, that as the back-water is greater, the greater the freshet is in the stream; by a practical change in the B. W. Co.'s wheel, the difficulty might always be accompanied with its own remedy. In high stages of the river, there is always a large amount of power wasted, because the machinery in most mills is adapted to a comparatively low stage of the stream; otherwise, a part of it must be useless during a considerable portion of the year. Now, if the B. W. Co.'s wheel were made broader, or, the buckets made larger, it would, with sufficient water, (which could always be obtained in high stages of the river) afford greater power.

From a perusal of the revised statutes of Mass. and the arguments made use of in a similar case to yours, on the Merrimac river, I am led to believe, that the principle has been admitted and acted upon by our courts; that a valuable mill privilege is not to be destroyed, or rendered entirely useless, because it may at certain times interfere, to

a limited extent, with an older privilege above. My impression is, that a great many mills in Massachusetts would be useless, if this were not the case. At the same time, no doubt all damages done to old privileges, either by loss of power, or necessary alterations of wheels, should be paid for, by those who cause them.

That you may be able to get others to investigate the foregoing conclusions, I have appended to this report the important facts and results obtained by the surveys and by my own investigations.

Very respectfully,

Your obedt. servt.,

E. S. CHESBROUGH.

ELEMENTS AND RESULTS OF CALCULATIONS.

Numbers of Stations.	OBSERVED.				Estimated, in case Day's Dam were removed, so as to lower the surface of the water there 2 feet.			The quantity passing per second was estimated at 800 Cubic Feet.
	Distance.	Average Depth.	Inclination	Estimated Perimeter in Contact with water.	Average Depth.	Inclination	Depres'n of surface at end.	
0 to 1	80	5.	.083	1776	3.13	.339	1.744	All the distances and heights are in feet.
1 " 2	100	4.5	–*.009	100	2.78	.034	1.701	
2 " 3	"	4.	.154	1268	2.51	.587	1.268	
3 " 4	"	6.5	.013	488	5.24	.025	1.256	
4 " 5	"	4.7	.061	865	3.49	.149	1.168	The width of the River is assumed at 100 feet.
5 " 6	"	4.	.046	402	2.87	.124	1.090	
6 " 7	"	4.	.068	595	2.96	.167	.991	
7 " 8	"	3.5	.098	574	2.58	.245	.844	
8 " 8.70	70	3.5	.010	82	2.66	.022	.832	
8.70 " 9	30	2.3	.149	815	1.61	.429	.552	
9 " 10	100	3.5	.092	539	3.07	.136	.508	
10 " 11	"	3.25	.178	800	2.79	.269	.417	
11 " 12	"	3.1	.067	273	2.70	.101	.383	
12 " 13	"	3.5	.033	193	3.12	.046	.369	
13 " 14	"	2.3	.087	145	1.96	.141	.315	
14 " 15	"	2.1	†.500	648	1.89	.703	.113	

* An apparent anomaly, but an ascertained fact.

† Imperfectly ascertained.

Heights of points of Observation above base line.

A 0,788′=$9\frac{7}{16}$ inches	D upper 1,201′=$14\frac{7}{16}$ in.	E upper 10,199′
B 0,976′=$11\frac{11}{16}$ "	D lower 1,277′=$15\frac{5}{16}$ "	E lower 11,129′
C 1,101′=$13\frac{3}{16}$ "	D outside1,864 =$22\frac{3}{8}$ "	

D upper, D outside, E upper and E lower, were not established at the same time, that A, B, C and D lower were.

Formula used in calculating the inclination of the snrface of the water.

$$I = \frac{Q^2 p}{aD^3W^3}$$

In which I = Inclination in Unity.

Q = Quantity of water passing per second in cubic feet.

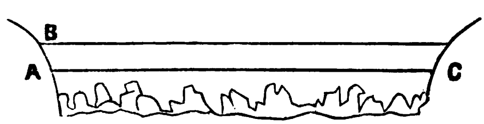
p = Perimeter in contact with water.

a = Practical coefficient, in this case assumed at 8,744.

D = Mean depth of water.

W = Width of stream—

p could not be measured; but was calculated by substituting for I in the equation, its known value from observation, as obtained by my brother's levels. Its value thus obtained, was used in all other cases to which the formula was applied. At first it might seem that this would not give a correct result; and in extreme cases either way it would not; but within the limits to which this formula has been applied, the error is exceedingly small, for p being the perimeter in



contact with water, is increased or diminished very little, by a rise or fall of the river, between the points A and B, (see Fig.) If the width of the stream A C be 50 times as great as the distance A B, then the difference between the value of p, when the surface of the river is at A, and when it is at B is 2 A B $= \frac{A\ C}{25}$, when the sides are nearly vertical, and the bottom coparatively even; but when the bottom is very rough as represented in the figure, and as is actually the case on the Housatonic, the actual length of p, between A and C, is often ten times the distance A C, and the difference 2 A B $=\frac{A\ C}{250}$, a quan-

tity so small, as to be of no practical importance, in the present instance.

The formula $I = \frac{Q^2 p}{a D^3 W^3}$ is not so accurate as the one given by Storrow in his treatise on Water Works, (p. 40) but is sufficiently so for practical purposes in cases like the present, and being much more convenient, has been used.

Storrow's formula $I = X \left(\frac{a\, Q\, w + b\, Q^2}{w^3}\right)$ in which

$X = p$ in the first formula.
$w = D\,W$ " "
I and Q = I and Q " "
a (practical coefficient) = .00004
b (" ") = .0001.

Comparative levels of the surface of the river as it was April 23d, 1849, at 2½ P. M., fixed points being established 100 feet apart at that time by several persons.

Station 0 (near Day's Dam,)	0,968 ft.	Station 8 + 70	1.492
" 1	1,051 "	" 9	1,641
" 2	1,042 "	" 10	1,733
" 3	1,196 "	" 10 + 50	1,846
" 4	1,209 "	" 11	1,911
" 5	1,270 "	" 12	1,978
" 6	1,316 "	" 13	2,011
" 7	1,384 "	" 14	2,098
" 8	1,482		

Observed heights of the surface of the water above the stations, in inches.

APRIL 19th, 1849.

Time. P. M.	A	B	C	D upper	D lower.	D outside	E upper	E lower.	REMARKS.
2 15	2¼"								
20		3¼"							
25	2½								
30		3½	4						
35	2⅞								
40		4	4⅛	5 8-16					
45	2¾				4 9-16				
50		3½	4	5 4-16			11	—0⅛	
55	2¾				4½				
3 00		3¾	4	5			10⅞	—0⅝	
05	2½				4 7-16				
10		3½	4	5⅜	4⅜		11	—0½	Flash boards, 3 in. high, put on
15	2⅝								
20		3⅛	4	5⅝			10⅞	—0⅝	
25	3				4⅜				
30		3¾	4¼	5⅝			11	—0⅝	
35	3¼				4½				
40		4	4⅜	5½			10⅞	—0⅝	
45	3¾		4½		4⅝				
50		4 7-16	4⅝	5½			10⅞	—0⅝	
55	4⅛		4⅞		4¾				
4 00		4⅞	5⅛	6			10¾	—0¾	
05	4⅛		5⅛		5⅛		10¾	—0¾	
10		4⅞	5⅛	6			10¾	—0¾	
15	4⅜		5		5		10¾	—0¾	
20		5	5¼	6⅛			10⅝	—0⅞	
25	4⅜		5⅜		5 5-16		10⅝	—0⅞	
30		5	5¼	6 5-16			10½	—0⅞	
35	4⅝		5¼		5 5-16		10½	—0⅞	
40		4¾	5¼	6⅛			10⅝	—0⅞	
45	4⅛		5⅞		5 5-16		10⅝	—0⅞	
50		4¾	5	6⅛			10⅝	—0⅞	
55	4		5⅛		5 3-16		10⅝	—0⅞	
5 00		4½	5	6			10½	—1.	
05	3¾		5		5 1-16		10½	—0⅞	
10		4⅜	4⅞	5⅝			10½	—0⅞	
15	3⅞		4⅞		4¾	1⅜	10½	—0⅞	
20		4½	4⅞	5¾			10½	—1.	
25	3⅞		4⅞		4⅞	1⅝	10½	—1.	
30		4¾	5	6			10⅜	—1.	
35	4		4⅞		4⅞	1¾	10⅜	—1.	
40		4½	4⅞	5 15-16			10⅜	—1.	
45	3⅞		4¾		4 13-16	1 9-16	10½	—0⅞	
50		4¾	4¾	5 9-16			10½	—0⅞	
55	4 1-16		5		5 3-16	1⅞	10½	—0⅞	
6 00		4½	5¼	6			10½	—0⅞	
05	4		4⅞		5	1⅝	10½	—0⅞	
10		4⅞		5⅞			10½	—1.	
15	4 1-16		5		4¾	1⅝	10½	—0⅞	
20		4¾		5⅞	5		10½	—0⅞	
25	4		5⅛	5⅞	4 15-16	1½	10⅝	—0⅞	
30		4¼		5 9-16			10⅝	—0⅞	
35	4		4⅞		4⅝	1 7-16	10¾	—0⅞	
40		4⅜		5¼			10⅞	—0¼	
45	3¾		4⅝		4¼	⅞	11	—0⅛	
50		4¼		5 9-16	4⅜		10⅞	—0⅛	
55	4		4½				10⅞	—0⅜	
7 00		3½					10⅞	—0⅛	
04				5¼		0	12	—0½	Mill stopped at 7.05.
07				4¼					
08				3⅜					
15			2¾			—1¼			
23	3⅛	2¾							
25			3						
30									
40				4¼	3⅜	0			
45	3¾		3 1-16					1 9-16	
50				4½	3¾	0¼			
8 00		4	3⅞	4½	3⅞	0⅜	13	2	
15	4⅛		4¼	4¾	4⅛	0¾	13⅛	2⅛	
30		4¼	4⅛	5 1-16	4⅛	1	13⅜	2⅜	
45	4¼		4⅝	5¼	4⅜	1¼	13⅜	2⅝	
9 00		4¾	5	5⅜	4¾	1⅜	13¾	2⅞	
06				5¾			14⅛	3	

Observed heights of the surface of the water above the stations, in inches.

APRIL 20th, 1849.

Time. P. M.	A	B	C	D upper	D lower	D outside	E upper	E lower	REMARKS.
8 00	5¾		7½						
05		6⅞							
10	5⅝		7½						
15		6⅞							
20	5¾		7⅝	8⅝	8¾	4⅝			
25		6¾					13¼	1⅞	
30	5⅞		7⅝	8⅝	7⅝	4⅝			
35		6¾					13⅝	1⅞	Day's wheel stopped.
40	6¼		7⅝						
45		7		8⅝	7¾	4⅝			
50	6½		7⅝				13¼	1⅞	
55		7							
9 00	6½		7⅝	8½	8	4⅝			
05		7					13	1¾	
10	6¼		7½						
15		7		8⅝	7⅝	4			
20	6¼		7⅜				13	1½	
25		6¾							
30	6⅛		7¼	8⅝	7⅝	3¾			
35		6¾					12¾	1½	
40	6		7⅛						
45		6¾		8⅛	7⅜	3¾			
50	6		7				12¾	1½	
55		6⅝							
10 00	6		7	7⅞	7⅛	3½			
05		6½					12⅝	1⅝	
10	6		7						
15		6½		7⅞	7⅛	3½			Flash boards removed.
20	5		6¼				12⅝	1¼	
22	4½								
25		5¼							
30	4¼		5⅝	7	6⅛	2⅞			Day's wheel started.
33	3⅞								
35		4¾					12¼	1⅛	
40	3½		5⅛						
45		4½		6¾	5⅝	2⅛			
50	3½		5¼				12⅝	1⅛	
55		4⅝							
11 00	3		4⅞	6¼	5⅝	2⅜			
05		4							
10	3		4¾	6½	5¼	2¼			
15		4					12⅝	1⅛	
20	3		4¾	6⅛	5¼	2¼			
25		4					12⅝	1⅛	
30	3		4¾	6	5¼	2¼			
35		4					12⅝	1⅛	
40	3		4¾	6⅛	5¼	2			
45		4					12¼	1	Day's wheel stopped.
50	3¾		5¼	6¼	5½	2¼			
55		4½					12⅝	1⅛	Day's wheel started.
12 00	3		5⅛	6⅛	5½	2⅛			
P.M. 05		4					12⅝	1⅛	
10	2¾		4	4⅞	4¼	1½			
15		37-16					12⅝	1½	
20	2½		4⅛	4⅞	4⅛	1¾			
25		3½					12⅝	1⅝	
30	2¾		4½	4⅞	4⅝	1⅝			
35		3¾					12½	1⅝	
40	3		4¼	5⅞	4¼	1½			
45		3⅞					12⅝	1¼	
50	3		4½	5⅝	4⅞	1¾			
55		4					12¼	1	
1 00	3		4⅝	5¾	5	1⅞			
05		4							
10			4½						

Observed heights of the surface of the water above the stations, in inches.

MAY 21st, 1849.

Time.	A	B	C	D upper	D lower	D outside	E upper	E lower	REMARKS.
12 00			1"						
03	1¾"								
10		1⅝"	1"	1⅛"	½"	1¾			
15							10⅞"		
20	1⅝"		1	1¼	⅝	1¾			
30		1⅝	1	1¼	¾	1¾			
40	1 11-16		1	1⅛	¾	1¾			
50		1⅝	1⅛						
1 00	1⅝		1⅛	1⅛	¾	1¾			
10		1¾	1	1¼	¾	1¾			
20	1⅝		1	1¼	¾	1⅞			
30		1¾	1⅛	1⅜	⅞	1⅞			
35							11"		Flash boards put on, 3 inches high, but probably did not touch the dam everywhere.
3 30	3⅞"								
40		3¾"	2⅞"	2¾"	2"	2¾"			
50	3⅞		2⅞	2⅞	2¼	2⅞			
4 00		3⅞	2⅞	2¾	2⅜	2⅞			
05							11"		
10	3⅞		2⅞	2⅞	2¼	2⅞			
20		3¾	2⅞						
30	3⅞		2⅞						
40		3⅞	2⅞						
50	4⅝		3⅞						Russel's wheel started.
5 00		4⅝	4						
10	4⅝								
20		5¼							
30	5								
35		5							

Referred to in the letters as Mr. Chesbrough's "REVISED CALCULATIONS."

WEST NEWTON, M ss., Sept. 3d, 1849.

DEAR SIR:

Since the date of my report to you of May last, I have paid much attention to the question of flowage caused by your dam on the Housatonic; indeed, the subject has seldom been out of my mind, in consequence of a correspondence I have had with Mr. Durant in relation to it. This correspondence has led me to a much more thorough investigation of the subject than was presented in my report; and I am satisfied, that two important alterations should be made in my calculations.

First, the quantity of water passing down the Housatonic on the 23d of April last, (when the pegs were driven for determining its surface inclination) was estimated a 800 cub. feet per second, when it should not have been over 600 feet per second. This was owing to

my using a wrong rule, of respectable, but not sufficient authority for determining this point.

Second, the natural width of the Housatonic at your dam was supposed, in my calculations, too large. Mr. Durant informs me, that it was only 75 feet, whereas I assumed it at 100 feet.

The first and most important question to be determined is, what would have been the level of the surface of the water just above your dam on the 23d of April last, had the natural channel been restored?

In solving this problem, it may be considered precisely the same as that of a stream partially obstructed by a bridge, having its abutments or piers, or both, built in the natural channel. Du Buat (Vol. I, pages 217, 218, and 219,) discusses this problem, and gives for its solution a very convenient formula, which, being adapted to English feet, is $\left(\frac{V^2}{58.74}+p\right)\left(K^2-1\right)$

$V=$ velocity per second.

$p=$inclination of the natural stream for the length of the piers and abutments, or narrowed part.

$K=$ratio between the natural and narrowed width of the stream.

In applying this formula to your dam, it is necessary to find the values of V, p, and K—V, as ascertained by dividing the quantity of water per second, 600 cub. feet, by the area of the section of the stream at the dam. The area will be the width multiplied by the average depth. The width Mr. Durant assumes at 132 feet, including your race-way. Let us call it in round numbers 130 feet. The depth, according to my brother's soundings just above and below the dam, show that the water must have had an average depth of not less than 2½ feet on the 23rd of April; but, to allow for irregularities, let us call it 2 feet. Then $V=\frac{600}{130\times 2}=2.308$ feet per second.

p, according to the formula $I=\frac{V^2}{8744\ R}$, would equal $\frac{2.308^2\times 30}{8744\times 1.94}=$ .00915 feet, it being understood, (Mr. Durant says) that the contracted part of the stream was 25 to 30 feet in length. This inclination, small as it is, is considerably more than would be obtained by Mr. Durant's formula $I=\frac{V^2}{12000\ R}$. I am satisfied that it is too little, however; and, as actual observation on the Housatonic has shown, the formula used gives on an average not more than one-tenth

or one-twelfth the actual amount. I prefer, therefore, to use .110 instead of .009 for the value of p.

K would be the present width of the stream including the raceway; say 130 feet divided by the natural width, say 75 feet. Hence, $K=1.733$.

Substituting then these values in the formula, $\left(\frac{V^2}{58.74}+p\right)\left(K^2-1\right)$ we have $\left(\frac{2.308^2}{58.74}+.110\right)\left(1.733^2-1\right)=.402$. If to this, the value of p be added, we shall have $.402+.110=.512$, or a little over 6 inches, as the height of the surface of the water just above your dam, above the height of the surface just below; the points supposed to be 30 feet apart.

According to my brother's levels, the fall at your dam on the 23rd of April last could not have been less than 26 inches, and must have been more; for it was 26 inches on the 6th of June, when there was a greater rise in the river than there was on the 23rd of April; and as the fall at the dam diminishes as the river rises, the fall must have been greater on the 23rd of April than on the 6th of June. Hence had the river been restored to its natural bed on the 23rd of April, the surface above the dam would, according to the foregoing computation, have fallen at least 20 inches. But, as the dam itself may cover boulders in their natural positions, and as these boulders could not possibly have been measured by my brother; but, at the same time, would have had a great effect on the inclination of the surface of the water, I will suppose that the surface of the water at the dam would have been lowered only 12 inches instead of 20, had the river been restored to its natural channel.

Starting then with a depression of 12 inches at your dam, and using the formula $I=\frac{Q^2\,p}{a\,D^3\,W^3}$, as explained in my report, I make a depression of the surface of the river at station 8.70, or the mouth of B. W. Co.'s tail race of about $5\frac{3}{4}$ inches.

The formula used has been objected to, but as I am unable to find anywhere a rule for *rough* channels, that expresses more faithfully the facts of nature, *when the same portion of the channel and the same quantity of water per second, and only different depths and velocities are taken into account*, I have, after much patient investigation, concluded to adopt it again. It is, I am aware, rather rude, but no precise rule

ever has, nor indeed can be, laid down for rough channels. Du Buat, and all others who have written on the subject, so far as my knowledge extends, give rules for smooth channels only. Du Buat made experiments to ascertain the resistance of irregular bodies, and was satisfied that a different rule must be applied to each different case.

Supposing the depression at the mouth of the B. W. and Co.'s tail race to be $5\frac{3}{4}$ inches, consequent upon the removal of your dam, the question is, what would be the depression at the B. W. and Co.'s wheel? Without attempting to arrive at this by any estimates, I would state, that at a comparatively low stage of the river, the fall between the wheel and the mouth of the race is known to be but 2 inches. At a higher stage of the river it would be less; and, if we suppose it annihilated altogether, the depression of the surface at the wheel, would on the 23rd of April last, have been $3\frac{3}{4}$ inches.

Annexed to this, is a tabular statement of my elements and calculations. Also one of another similar set of calculations, supposing the depression of the surface of the water at your dam by restoring the river to its natural channel, would have been only 6 inches on the 23rd of April last.

Very respectfully,

Your obedient servant,

HORACE H. DAY, Esq. E. S. CHESBROUGH.

Referred to in the letters as Mr. Chesbrough's "REVISED CALCULATIONS."

ELEMENTS AND RESULTS OF CALCULATIONS.

STATIONS.	OBSERVED.				Estimated in case dam were removed so as to lower surface of water 1 foot.			
	Distances.	Average depth.	Inclination.	Estimated perimeter in contact with water.	Average depth.	Inclination.	Depression of surface at end	
0 to 1	80	5.	.083	3150	4.0372	.1575	.8508	Quantity of water passing per second being 600 cubic feet. Depression of surface just above the dam assumed at 12 inches.
1 " 2	100	4.5	—.009	—199	3.5695	—.0180	.8598	
" 3	"	4.	.154	2393	3.1462	.3164	.6974	
" 4	"	6.5	.013	867	5.7304	.01898	.69142	
" 5	"	4.7	.061	1538	3.9541	.1024	.65002	
" 6	"	4.	.046	715	3.2930	.0824	.61362	
" 7	"	4.	.068	1057	3.3357	.117	.56462	
" 8	"	3.5	.098	1021	2.8976	.1728	.48982	
" 8.70	70	3.3	.010	149	2.9384	.01694	.48288	or $5\frac{3}{4}$ in.' at the mouth of the B. W. Co's tail-race.
" 9	30	2.3	.149	1468	1.8180	.3012	.33068	

STATIONS.	OBSERVED. Distances.	Average depth.	Inclination.	Estimated perimeter in contact with water.	Estimated for a depression of surface of water one half foot. Average depth.	Inclination.	Depression of surface at end.	Quantity of water = 600 cubic feet. Depression of surface just above the dam assumed at 6 inches.
0 to 1	80	5.	.083	3150	4.51485	.1127	.4703	
1 " 2	100	4.5	—.009	—199	4 03146	—.01252	.47382	
" 3	"	4.	.154	2393	3.55848	.2186	.40922	
" 4	"	6.5	.013	867	6.09217	.01578	.40644	
" 5	"	4.7	.061	1538	4.30276	.07940	.38804	
" 6	"	4.	.046	715	3.62016	.06240	.37164	
" 7	"	4.	.068	1057	3.63950	.0984	.34124	
" 8	"	3.5	.098	1021	3.17076	.132	.30724	
8 " 8.70	70	3.5	.010	149	3.191436	.0132	.30404	or 3⅜ in. at the mouth of the B. W. Co's tail-race.
8.70 " 9	30	2.3	.149	1468	2.02986	.2168	.23624	

Referred to in the letters as "Mr. Culver's Letter."

Gt. Barrington, Aug. 21st, 1849.

Mr. H. H Day—

Dear Sir:

Yours of the 18th came to hand yesterday, and order for belts, in rather a bad time for us, as the Berkshire Woolen Co. shut down their gates yesterday afternoon, and we had not water sufficient to run last night at all; however, we shall make them to-day and cure them this night, and send them by the passenger train to-morrow (Tuesday.) Richard, and a number with him, took measurements yesterday afternoon and night. Yesterday, at about 5 o'clock, P. M., Richard went up to the race-way of the B. W. Co., together with your Father, Noxon, Smith, and Tyer; and there was not a particle of water within 72 feet of the wheel, *i. e.*, the race-way was perfectly dry for 72 feet, and at the same time there was a full sheet of water passing over your dam; your gates were shut down at the same time.

Respectfuly, Yours,

C. B. CULVER.